싱글과 멀티페이즈 전원공급장치의
효율과 신뢰성을 측정하기 위한 최신 솔루션

텍트로닉스
이기웅 이사

KEITHLEY
A Tektronix Company

Tektronix®

Agenda

- Power Basics – Electronic converter and SMPS
- Power Measurement
- Advanced Power Analysis solution
- Power Analyzer - Key applications/Wiring Single,Multi-Phase measurement/Wireless Charging System/Standby Power
- Measurement Tips: Differential and floating measurement /Current Probe wire wrapping

Power Basics

Tektronix®

Power Basics

- Power electronic converters can be found wherever there is a need to **modify the form of electrical energy** (i.e modify its voltage, current or frequency).
- The power range of these converters is from some milliwatts (as in a mobile phone) to hundreds of megawatts (e.g in a HVDC transmission system).
- In modern systems the conversion is performed with semiconductor switching devices such as **diodes, thyristors and transistors**
- Two types of converters: **linear or switching supply**
- A **switched-mode power supply** (also **switching-mode power supply**, **SMPS**, or simply **switcher**) is an electronic power supply unit that incorporates a switching regulator in order to provide the required output voltage
- An SMPS is actually a power converter that transmits power from a source (e.g., a battery) to a load (e.g., a personal computer) with **ideally no losses**.

SMPS Basics

- SMPS can be classified into **4 types** based on the input and output
  - AC in, DC out: Rectifier, off-line converter input stage
  - DC in, DC out: chopper or DC to DC converter
  - AC in, AC out: cycloconverter, frequency changer
  - DC in, AC out: inverter
- Switch Mode Power Supplies (SMPS) have become the **dominant architecture** for the supplies used in most electronics systems
- SMPS Benefits
  - More efficient (Green Power)
  - Wide AC Input Range
  - Smaller size, lower weight
  - Reduced cost for large amounts of power delivered
- Measurement, Characterization and Analysis are a challenge
  - Stringent efficiency and performance requirements
  - Increasing power density
  - Faster switching speeds of modern power semiconductors
  - Tedious calculations needed for a sophisticated analysis.

SMPS Types – Power vs. Efficiency vs. Cost

Type	Power (Watts)	Typical Efficiency	Relative Cost	Input Range (Volts)	Isolation	Energy Storage	Voltage Relation
Buck	0-1000	75%	1.0	5 – 1000	N	Single Inductor	Out < In
Boost	0 – 150	78%	1.0	6 – 600	N	Single Inductor	Out > In
Buck-boost	0 – 150	78%	1.0	5 – 600	N	Single Inductor	Any inverted *1
Split-Pi Boost-Buck	0 - 2000	95%	> 2.0	10 – 100	N	2 Inductors + 3 Capacitors	Up or Down *2
Flyback	0 – 150	78%	1.0	5 – 600	Y	Transformer	Up or down *3
Push-Pull	100 – 1000	72%	1.75	50 – 1000	Y		
Half Bridge	0 – 500	72%	1.9	50 – 1000	Y		
Full Bridge	400 – 2000	69%	> 2.0	50 – 1000	Y		
Half-Forward	0 – 250	75%	1.2	5 – 500	&	Transformer + Inductor	
Forward		78%		60 – 200	Y	Transformer + Inductor	Any Fixed *4

1. Inverted output voltage. Voltage ratio depend on duty cycle.
2. Bi-directional power control In or Out.
3. Multiple outputs.
4. Multiple outputs.

Power Basics

- **AC/DC converters (rectifiers)** are used every time an *electronic device is connected to the mains (computer, television,...)*

- **DC/DC converters (chopper)** are used in most mobile devices (mobile phone, pda...) to maintain the voltage at a fixed value whatever the charge level of the battery is. These converters are also used for *electronic isolation and power factor correction.*

KEITHLEY
A Tektronix Company

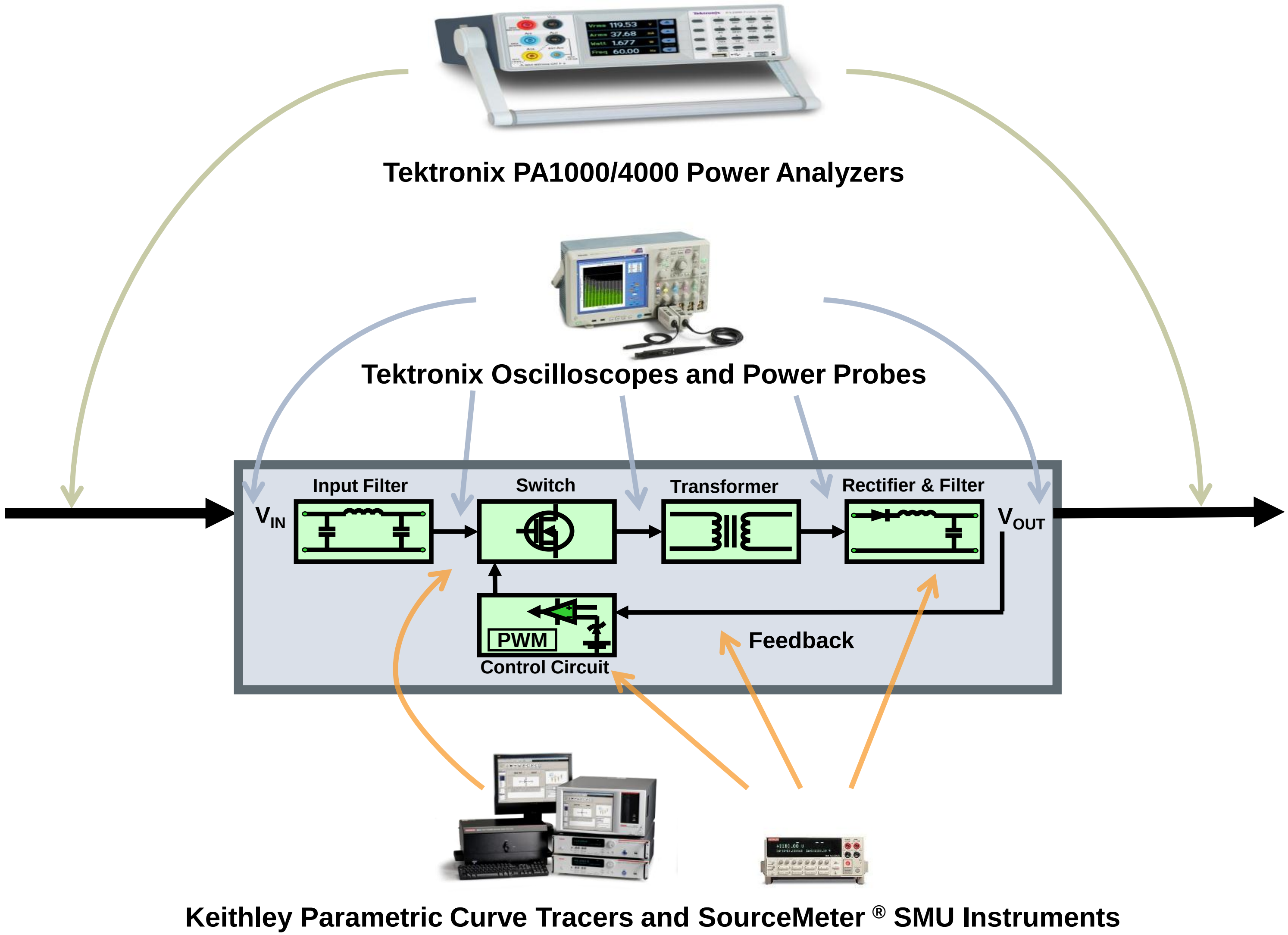
Tektronix®

Power Basics

- **AC/AC converters (cycloconverter)** are used to change either the voltage level or the frequency (international power adapters, light dimmer). In power distribution networks AC/AC converters may be used to exchange power between utility frequency 50 Hz and 60 Hz power grids.

- **DC/AC converters (inverters)** are used primarily in *UPS or emergency light*. During normal electricity condition, the electricity will charge the DC battery. During blackout time, the DC battery will be used to produce AC electricity at its output to power up the appliances.

Need Power Analyzer & scope to measure

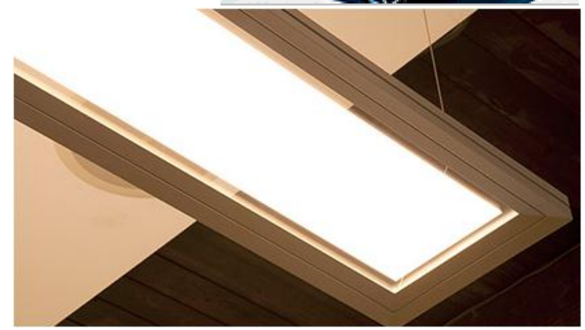


Tektronix®

Power Application Segments

Power Convertors in Electronic Devices

- Switching Power Supplies
  - AC/DC, DC/DC
- Automotive
  - DC/DC Converter
  - Power Inverter
  - Mobile / battery power
- Electronic Ballast
- LED lighting
- Consumer Electronics
- Industrial

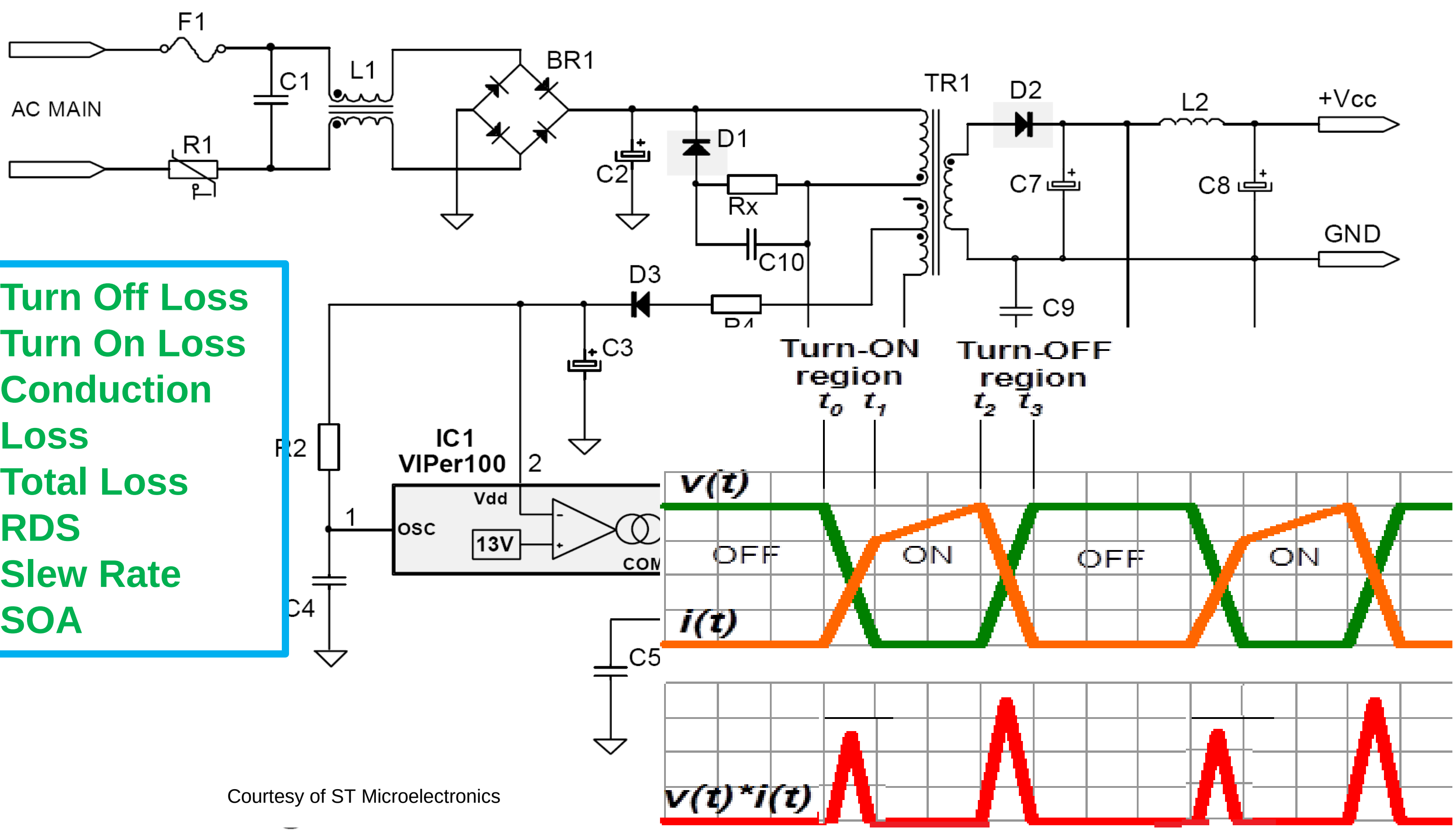


KEITHLEY A Tektronix Company

Tektronix

Power Measurements & Challenges
Typical SMPS Circuit

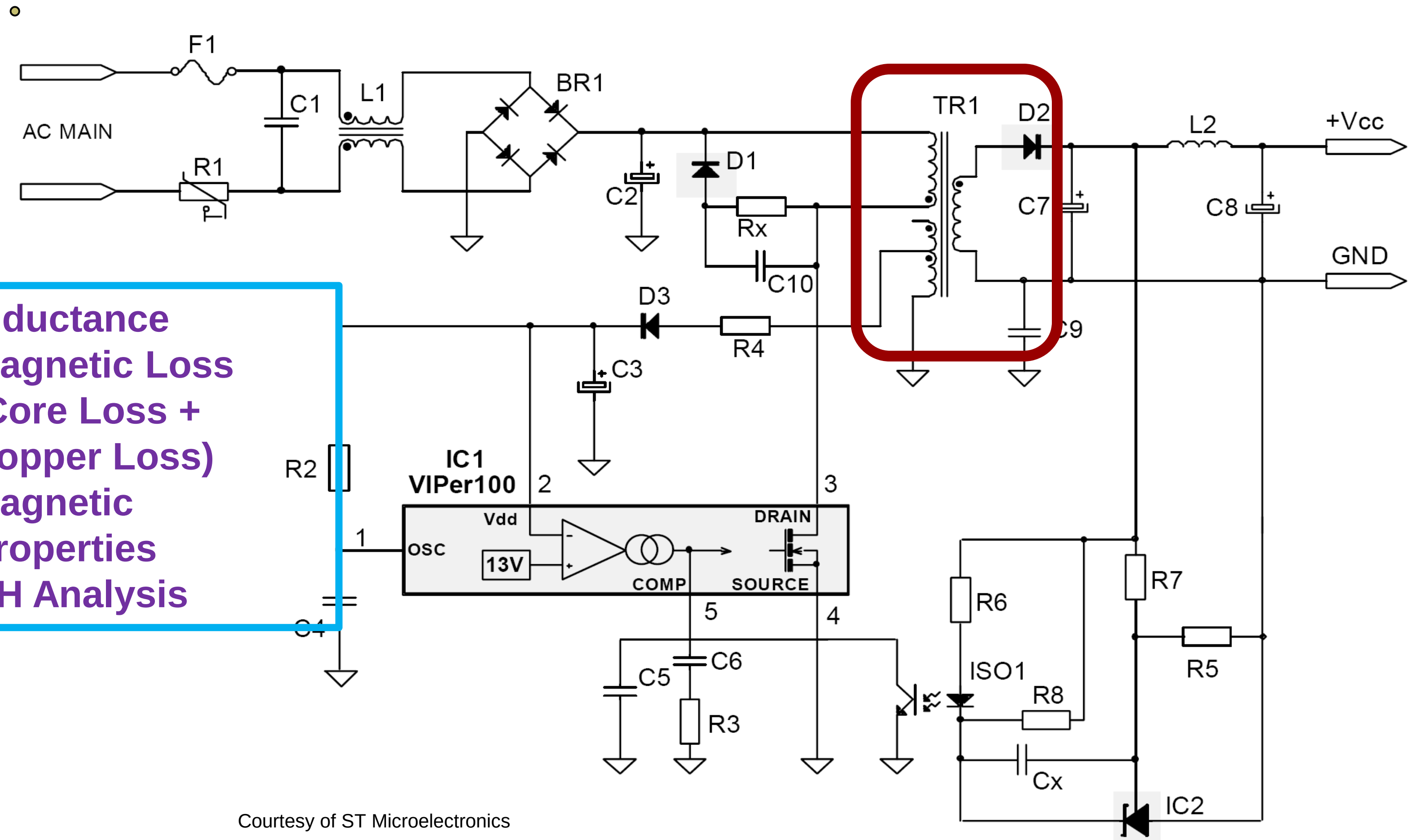
-



Turn Off Loss
Turn On Loss
Conduction Loss
Total Loss
RDS
Slew Rate
SOA

Courtesy of ST Microelectronics

Power Measurements & Challenges
Typical SMPS Circuit

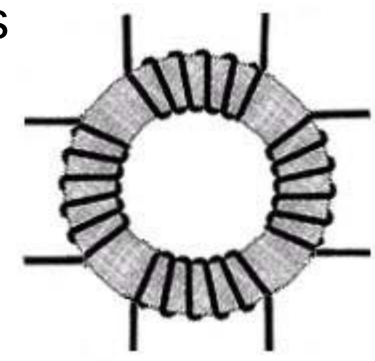


- **Inductance**
- **Magnetic Loss (Core Loss + Copper Loss)**
- **Magnetic Properties**
- **BH Analysis**

Courtesy of ST Microelectronics

Inductance

- Used as Energy Storage devices, Filters, Transformers
- Inductance depends on
  - Current and voltage source
  - Excitation signal
  - Wave shape
  - Frequency of Operation



- Traditional methods of measurements (e.g.: LCR meter) does not provide a picture of real-world (in-circuit) operation
- Inductance is defined

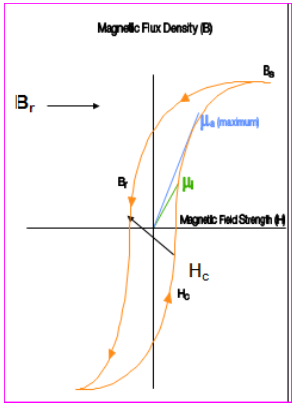
$$L = \frac{\int - e\,dt}{I}\ Henry$$

- L is the inductance
- e is the voltage across the inductor
- I is the current though the inductor
- dt is the rate of change in a signal; the slew rate

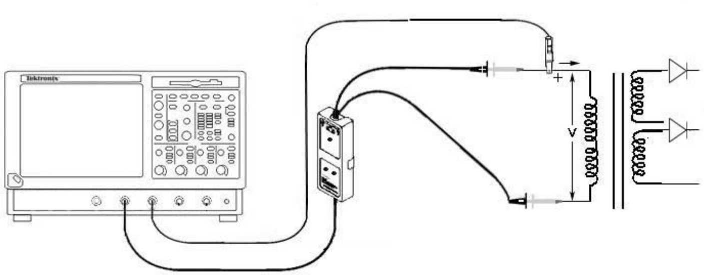
Magnetic Loss

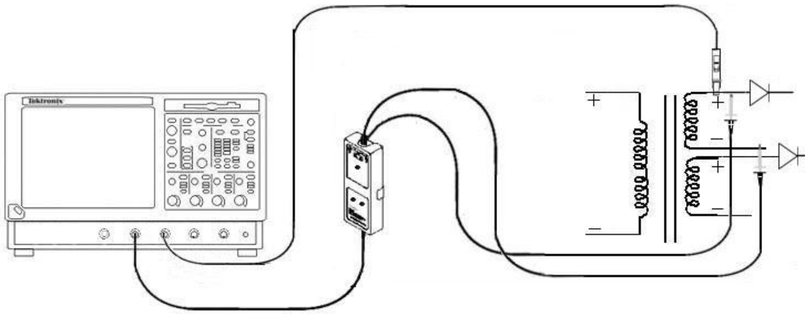
- Magnetic loss affects the efficiency, reliability and thermal performance of the Power Supply
- Focus on the inductors and transformer
  - Inductance
  - Magnetic Power Loss (Core Loss + Copper Loss)
  - Magnetic Properties

  *Core Loss = Eddy Current Loss + Hysteresis Loss



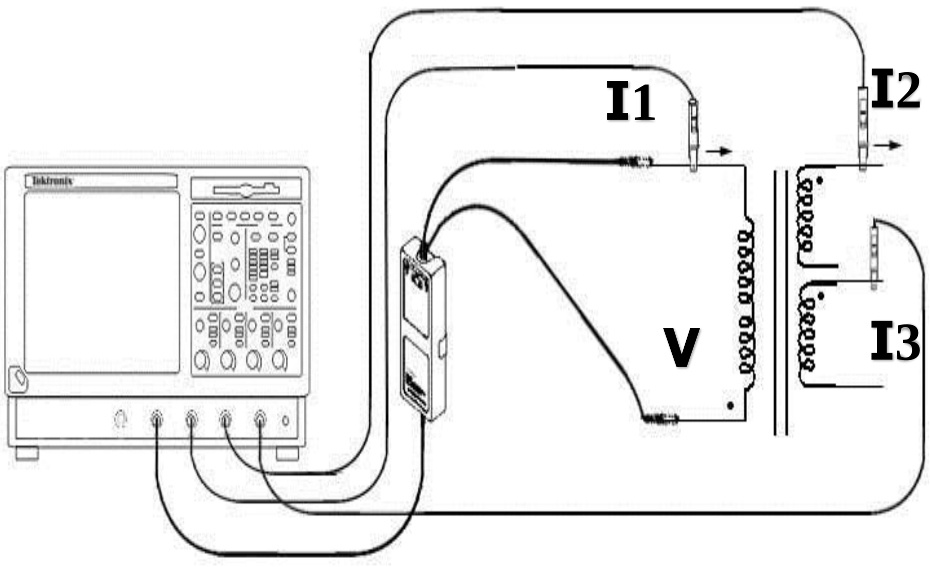
- Measurements on a single-winding inductor, multiple-winding inductor or a transformer





Magnetic Property measurement in a transformer

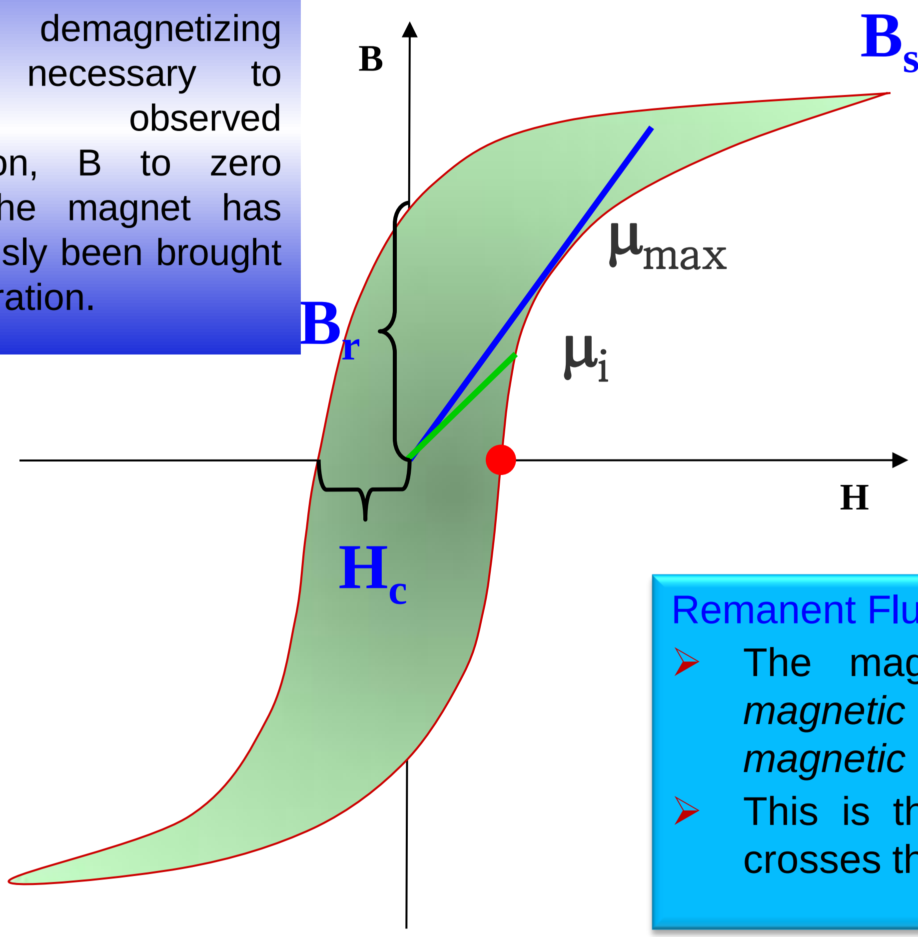
- Measure voltage across the primary
- Measure current through each of the winding of transformer
  - Current probe should in the direction of the current flow
- Input Physical parameter of transformer
- Run magnetic property measurement



Magnetic Measurements - Passive Component

Coercive force(Hc)

The demagnetizing force, necessary to reduce observed induction, B to zero after the magnet has previously been brought to saturation.



Hysterersis in a typical magnetic material

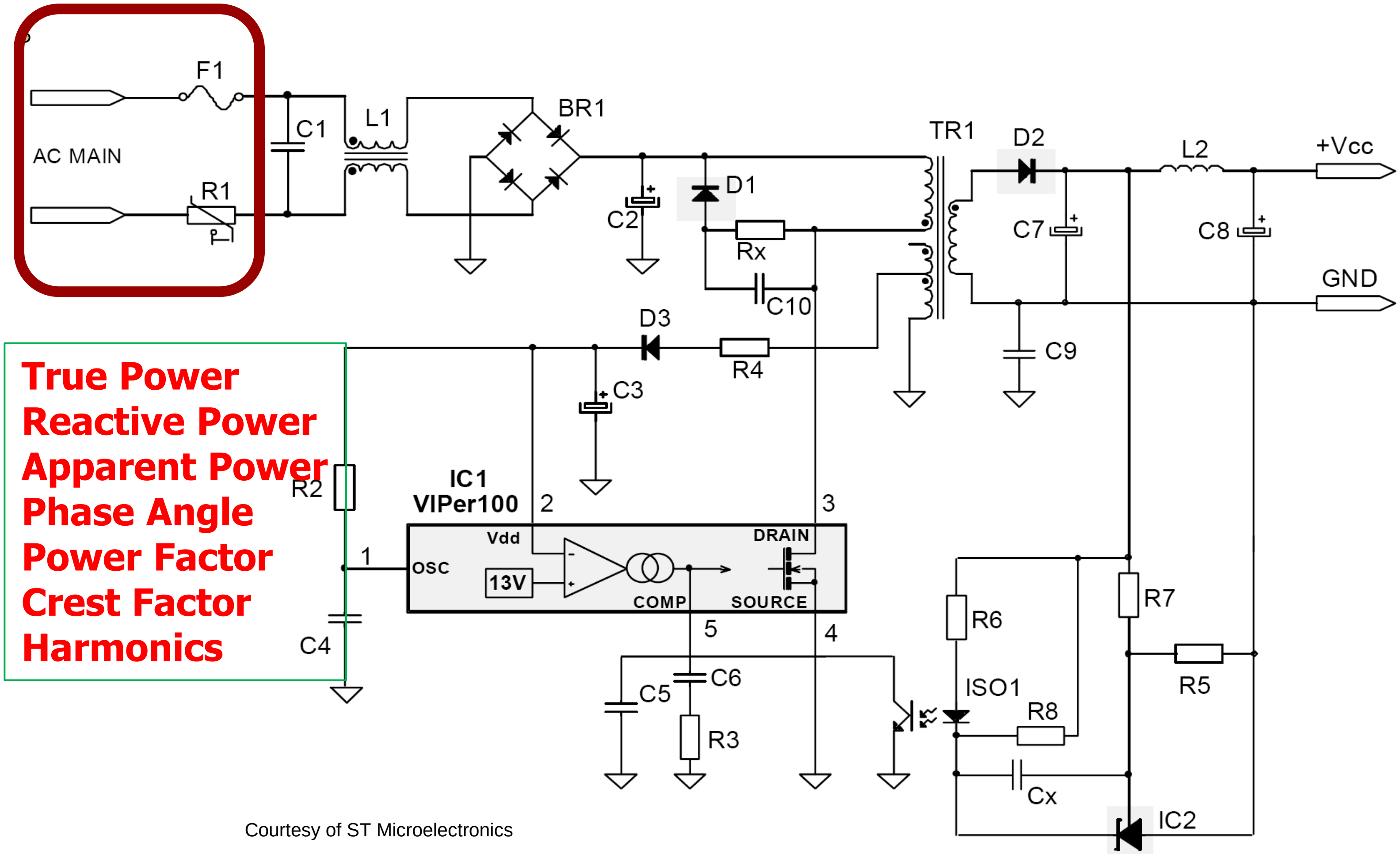
- B_s is the satutation Flux Density
- B_r is the remanence Flux Density
- H_c is the coercitive force
- μ_i is initial permeability
- μ_a is the Max Amplitude permeability

Remanent Flux(Br)

- The magnetic induction that remains in a *magnetic circuit* after the removal of an applied *magnetic force*.
- This is the point at which the hysteresis loop crosses the B axis at zero magnetic force (H)

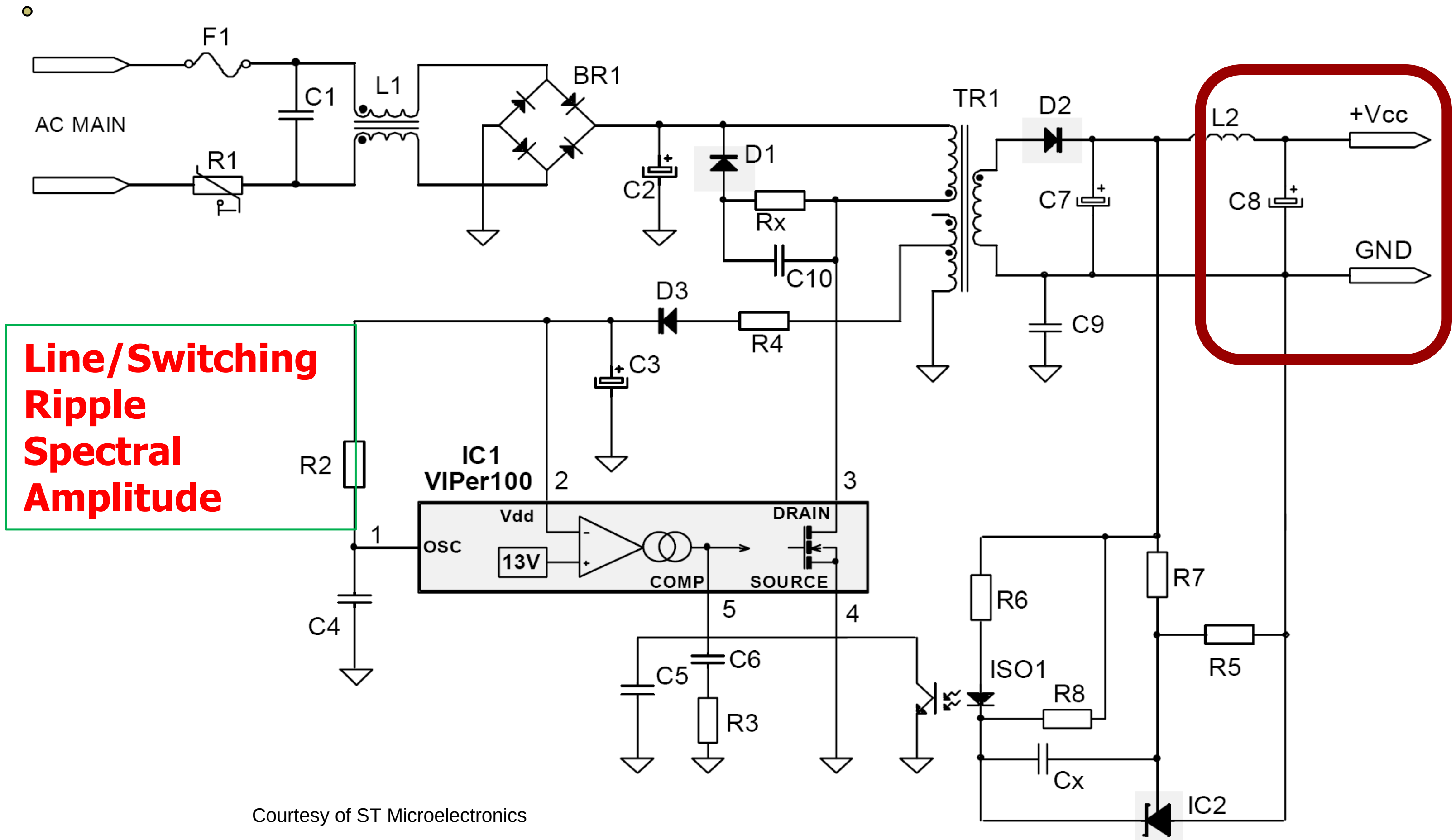
Power Measurements & Challenges
Typical SMPS Circuit

- **True Power**
- **Reactive Power**
- **Apparent Power**
- **Phase Angle**
- **Power Factor**
- **Crest Factor**
- **Harmonics**



Courtesy of ST Microelectronics

Power Measurements & Challenges
Typical SMPS Circuit



Courtesy of ST Microelectronics

KEITHLEY A Tektronix Company

Tektronix

Advanced Power Analysis Solution

DPOPWR new additions /Enhancements

- Grouping of measurements - Multiple measurements can RUN at the same time in a single acquisition, so user gets to have optimal grouping results.
- New measurements such as Inrush current, Capacitance, Reactive power, Dynamic resistance and Switching loss trajectory plot are added. This will provide more insight to Input/output Characterization.
- Custom source Autoset for vertical and horizontal will setup the scope parameters automatically, which will increase the productivity.
- New Plots (Time trend, SWL Trajectory Plot). Interactive Plot features provides cursors linkage to the values, Saves data and image.
- Automatic de-gauss and de-skew utilities.
- Reference waveform support 23/25 measurements.
- A single printable (.mht) report provides an easy way of generating test reports. Report append feature provides reports of many runs in single file. (Eliminates RG tool dependency)
- On the fly measurement addition and deletion. On the fly configuration changes. No need to stop the test for adding/deleting/configuration changes.
- Performance improvement by around 2X (compared to existing application)

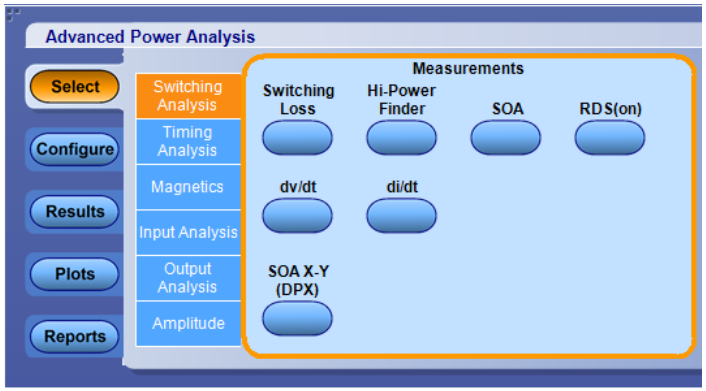
Advanced Power Analysis Solution

DPOPWR new additions /Enhancements

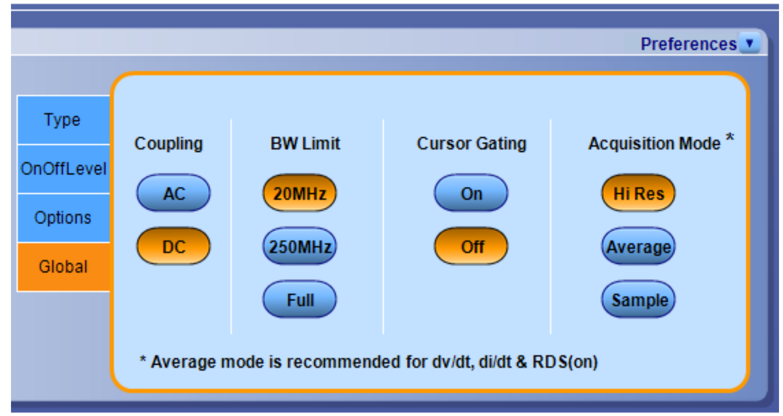
- Added Conduction Loss results.
- Switching loss T On, T off and Conduction loss result per Cycle on the Plot.
- Added a PFC checkbox under SWL configuration tab to analyze PFC signals
- First 10 SOA Mask violation waveforms are stored automatically.
- Added Voltage Harmonics measurement.
- Supported up to 100th harmonics to all Current Harmonics Standards.
- Added Amplitude measurements
- Add Phase Angle measurement to Input analysis
- Added Skew measurement.
- Auto detection of probe and display skew value
- Provided Auto Zero feature for Shunt
- Provided auto frequency computation for CH and VH measurements
- Time trend plot, switching loss and SOA plot cursor linkage to actual waveforms.
- GPIB support

Switching Analysis- Measurement Setup

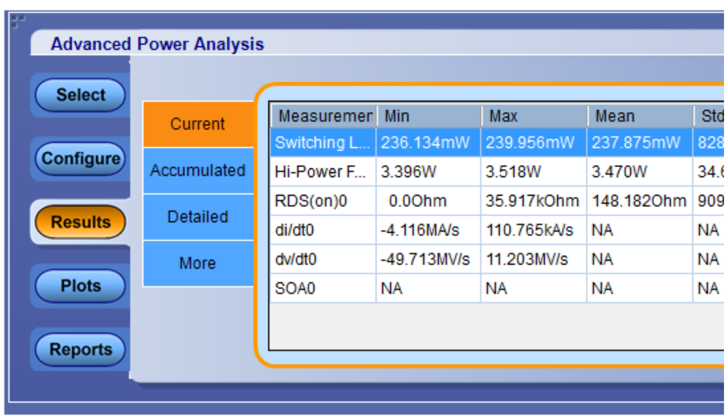
- Multiple Measurements



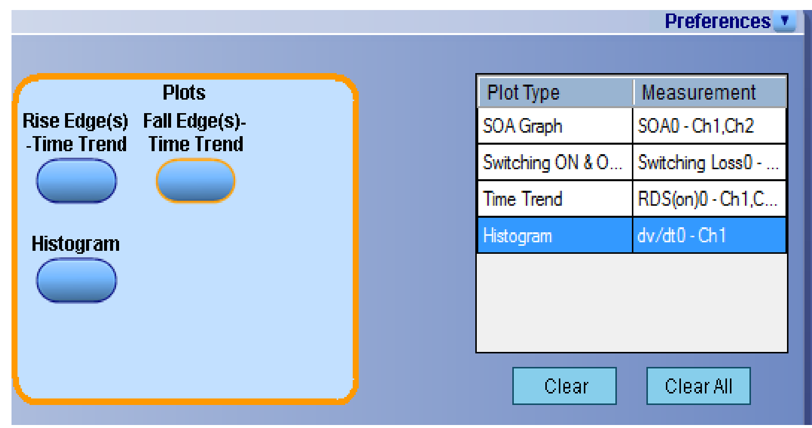
- Global Configuration



- Result Summary



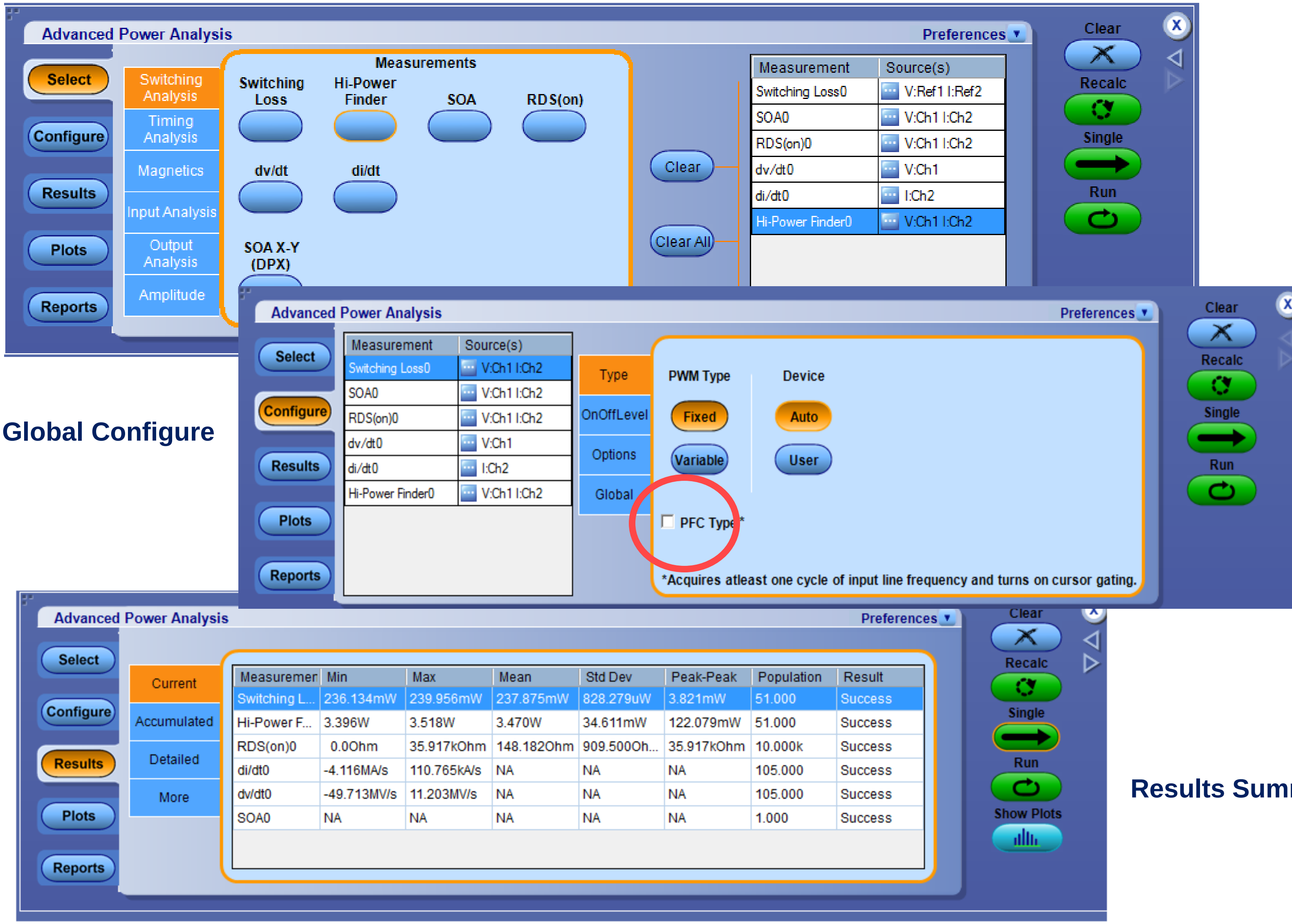
- Plots



KEITHLEY
A Tektronix Company

Tektronix®

Switching Analysis- Grouping

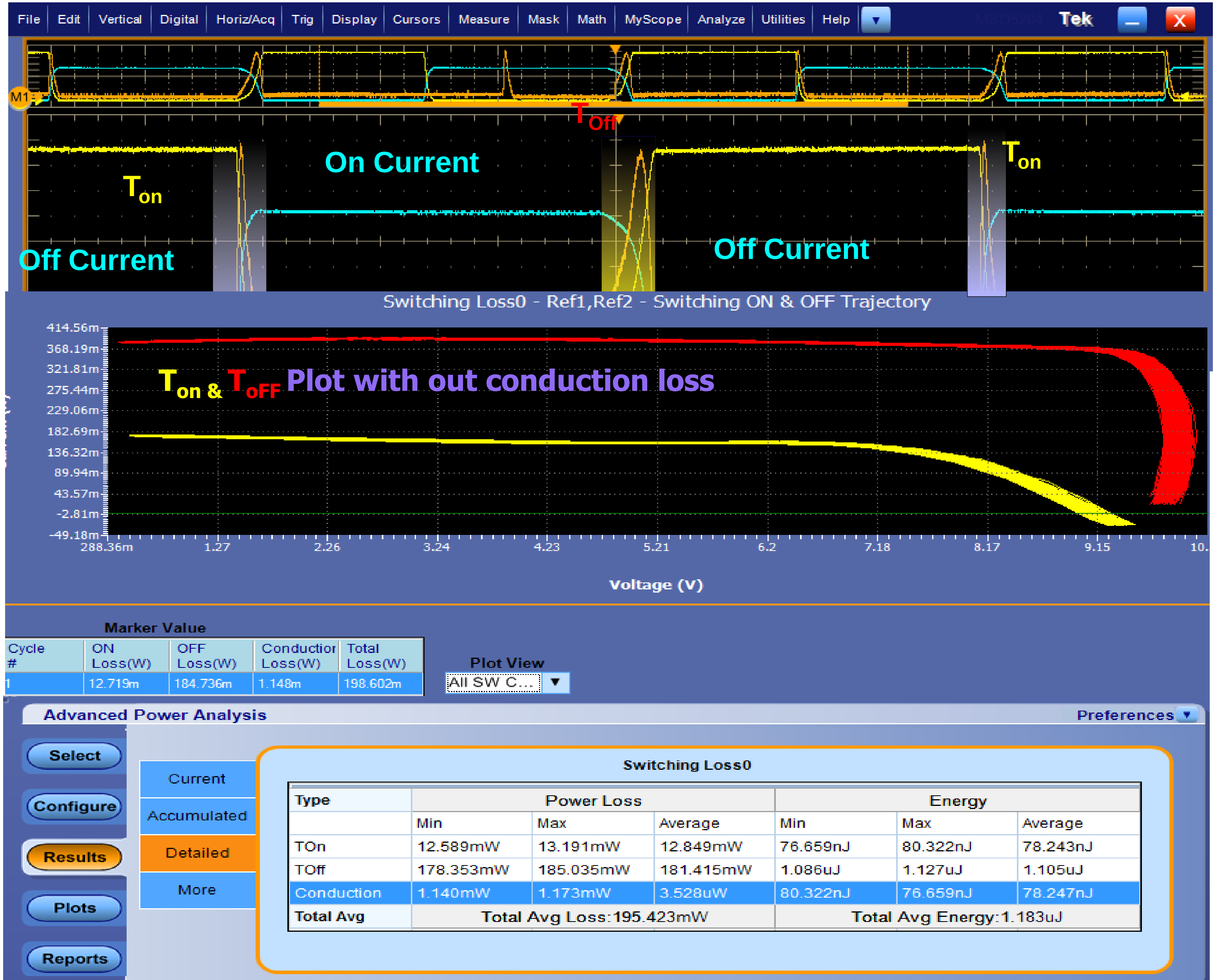


Global Configure

Results Summary

Tektronix®

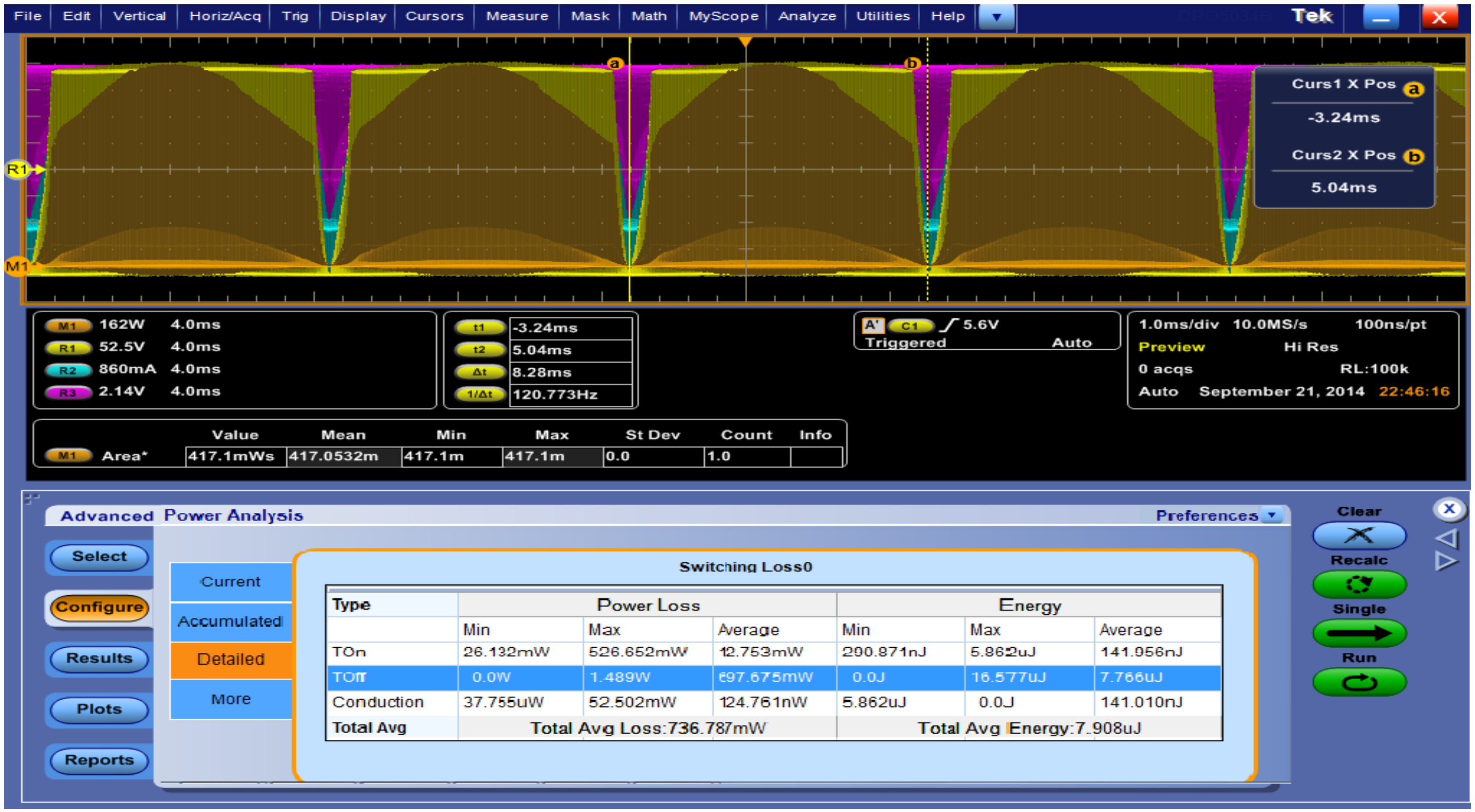
Switching Analysis- Switching Loss



Tektronix

Switching Analysis- PFC Circuit

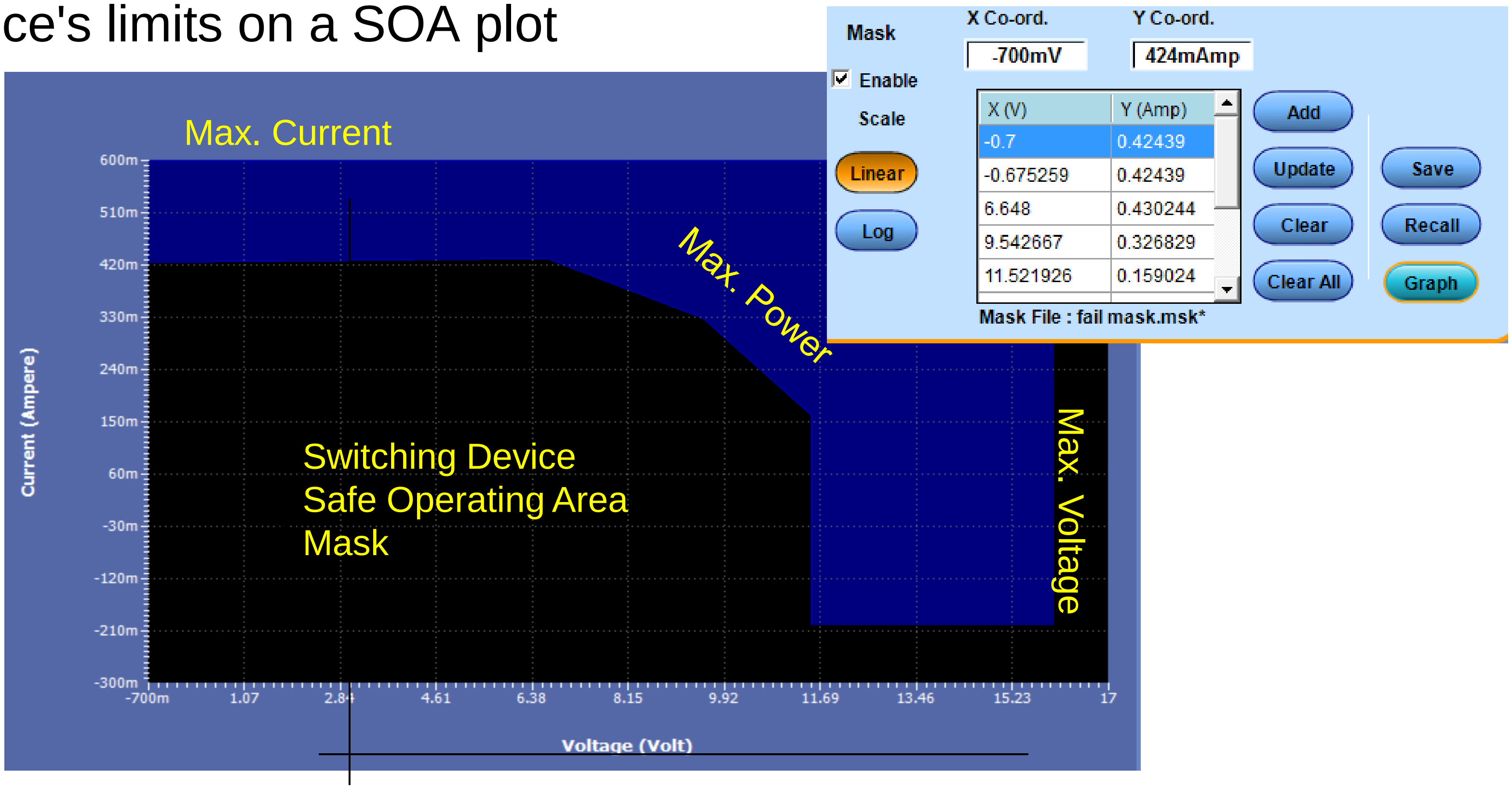
Buck, boost, fly back and other converter topologies are used in active PFC circuits



Active PFC offers better THD and significantly smaller in size, operates at a higher switching frequency than the 50Hz/60Hz line frequency

Switching Analysis- SOA Mask

- Switching device operating region
  - Plot of voltage versus current
- SOA mask is a graphic representation of the switching device's limits on a SOA plot

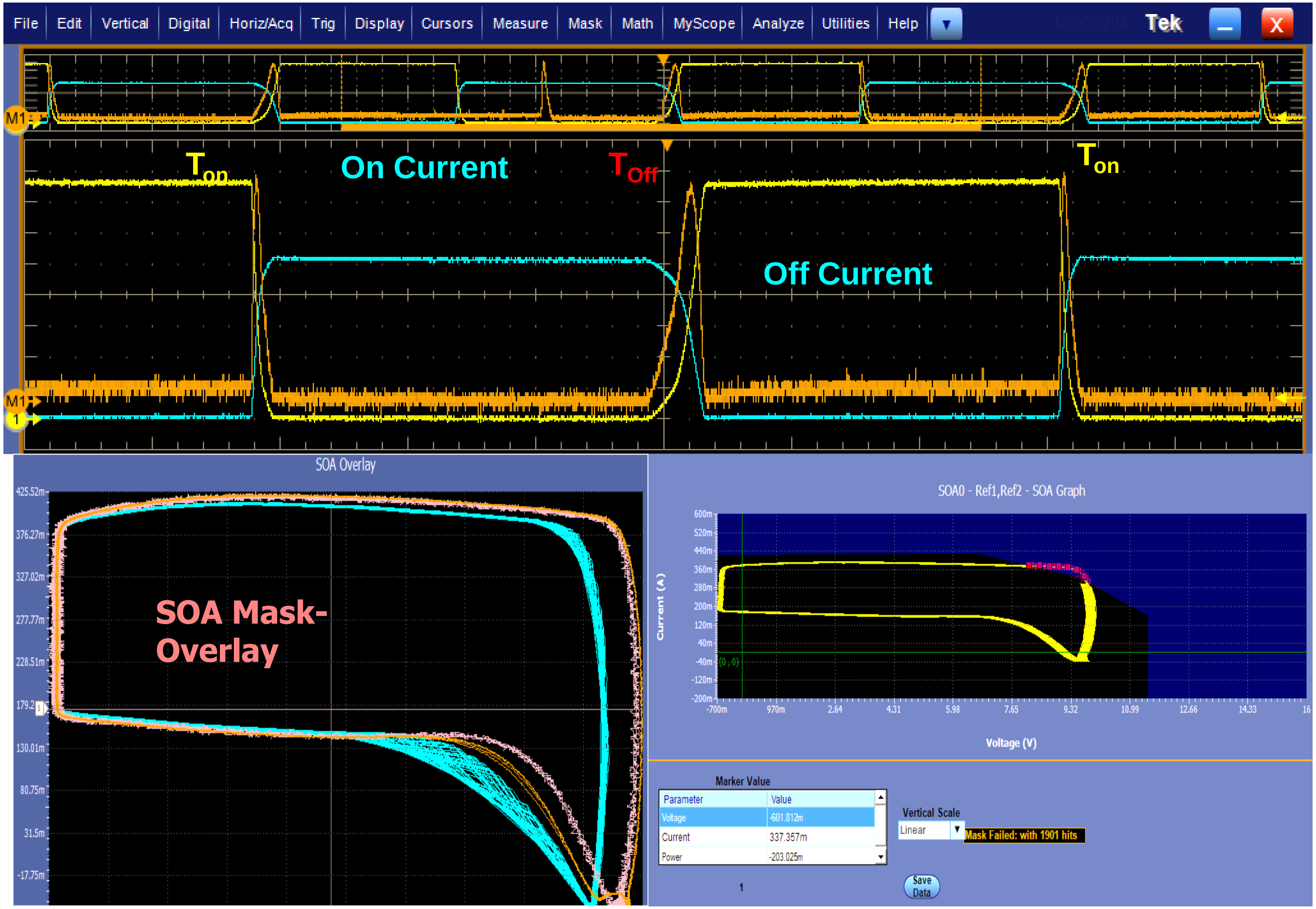


Volts

KEITHLEY
A Tektronix Company

Tektronix®

Switching Analysis- SOA Mask Testing



Tektronix®

Magnetic Analysis- Grouping

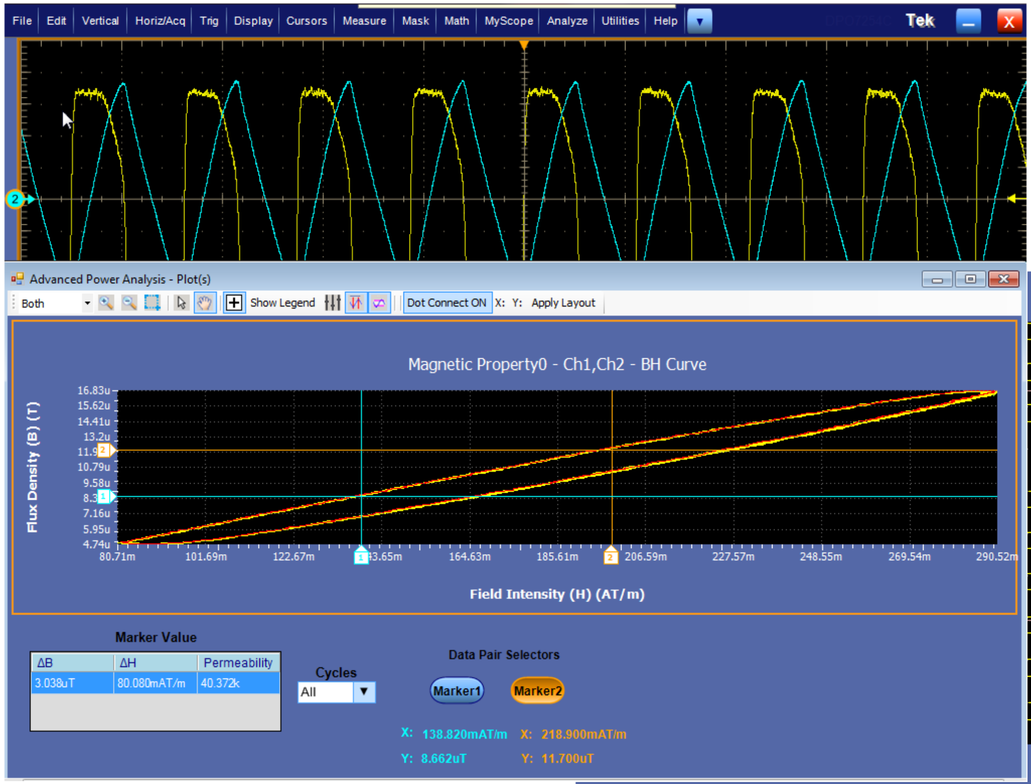
Magnetic Measurements

Configure Plots

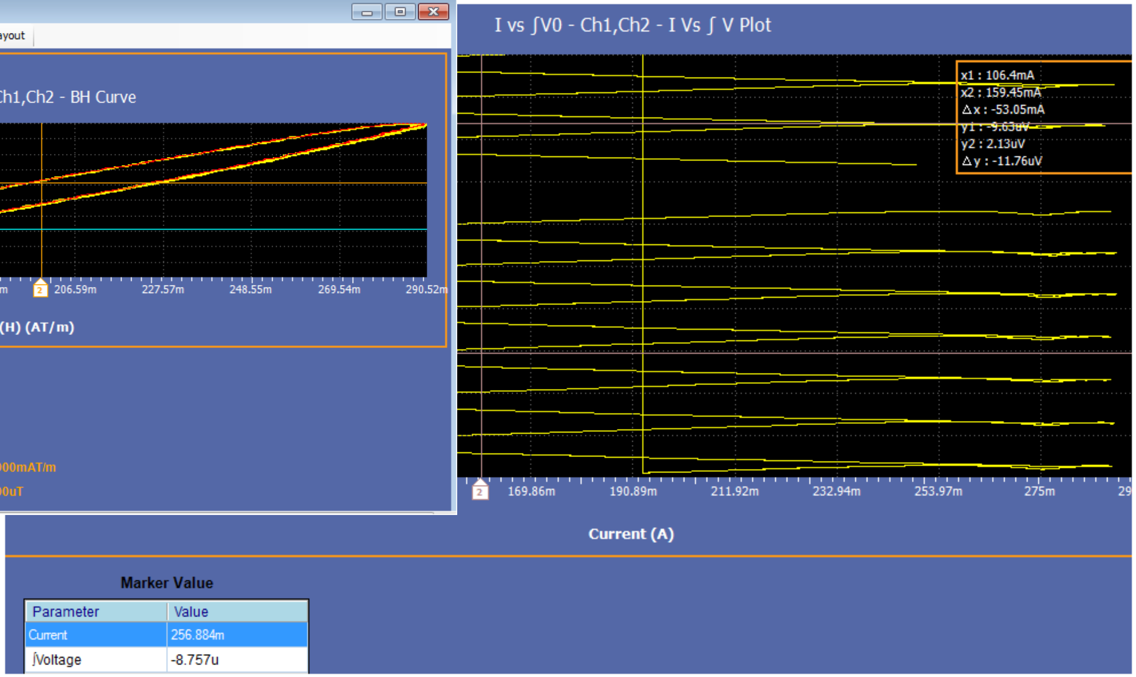
Group Results

Magnetic Analysis- BH Curve

- An Interactive BH plot provides more insight to magnetic component.

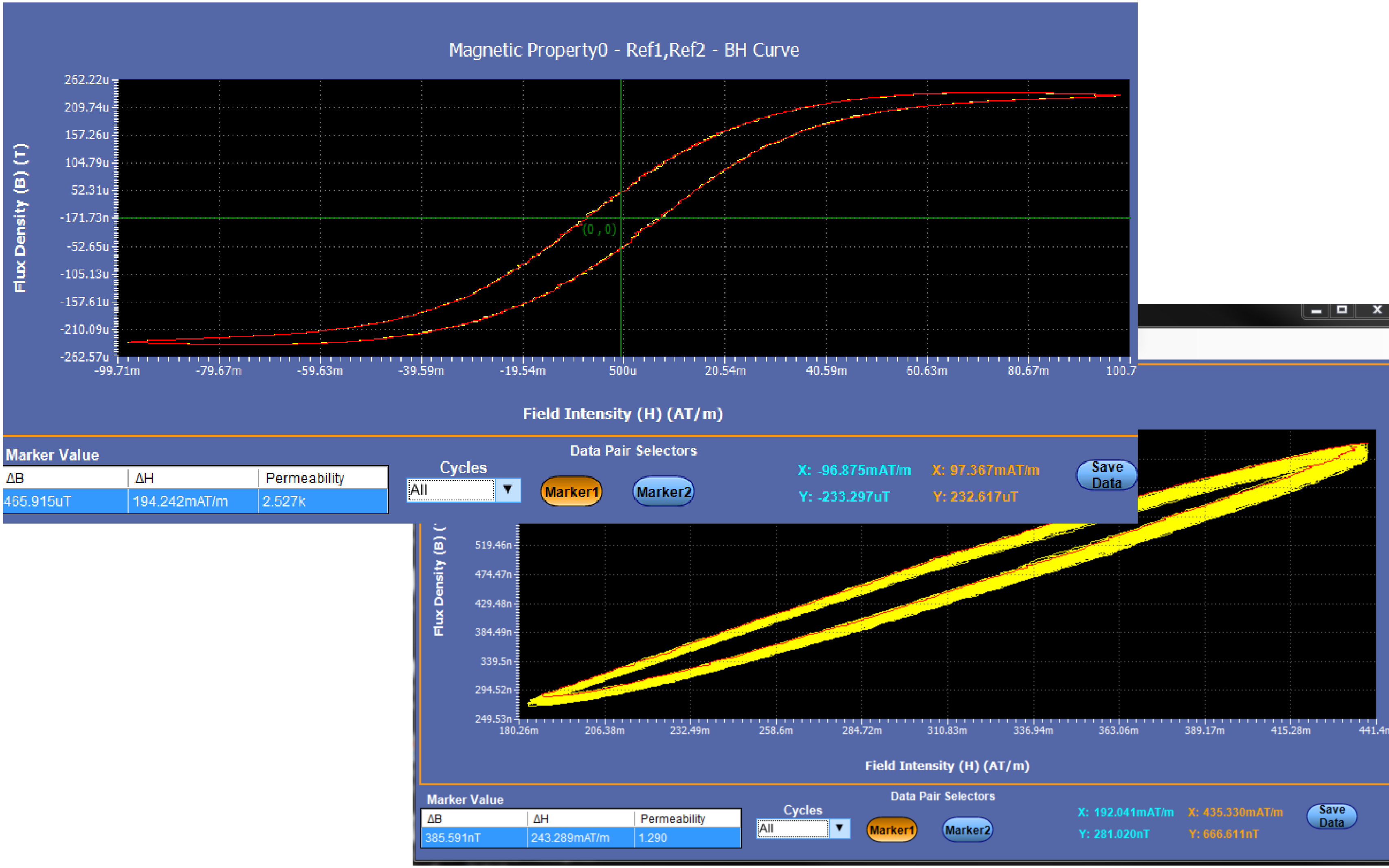


B-H plot for single winding inductor



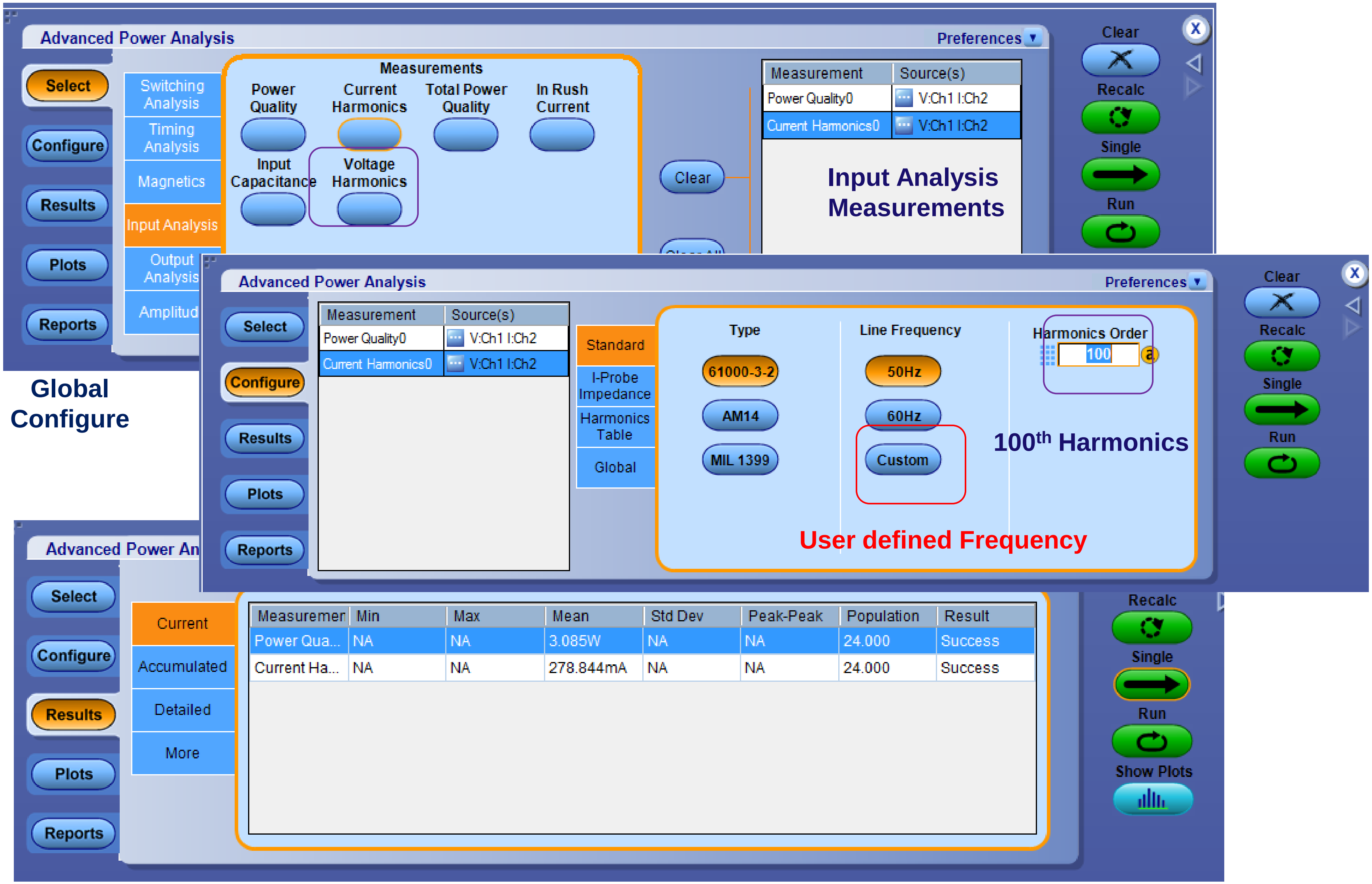
Magnetic Analysis- BH Curve

- An Interactive BH plot provides more insight to magnetic component.



Input Analysis- Grouping

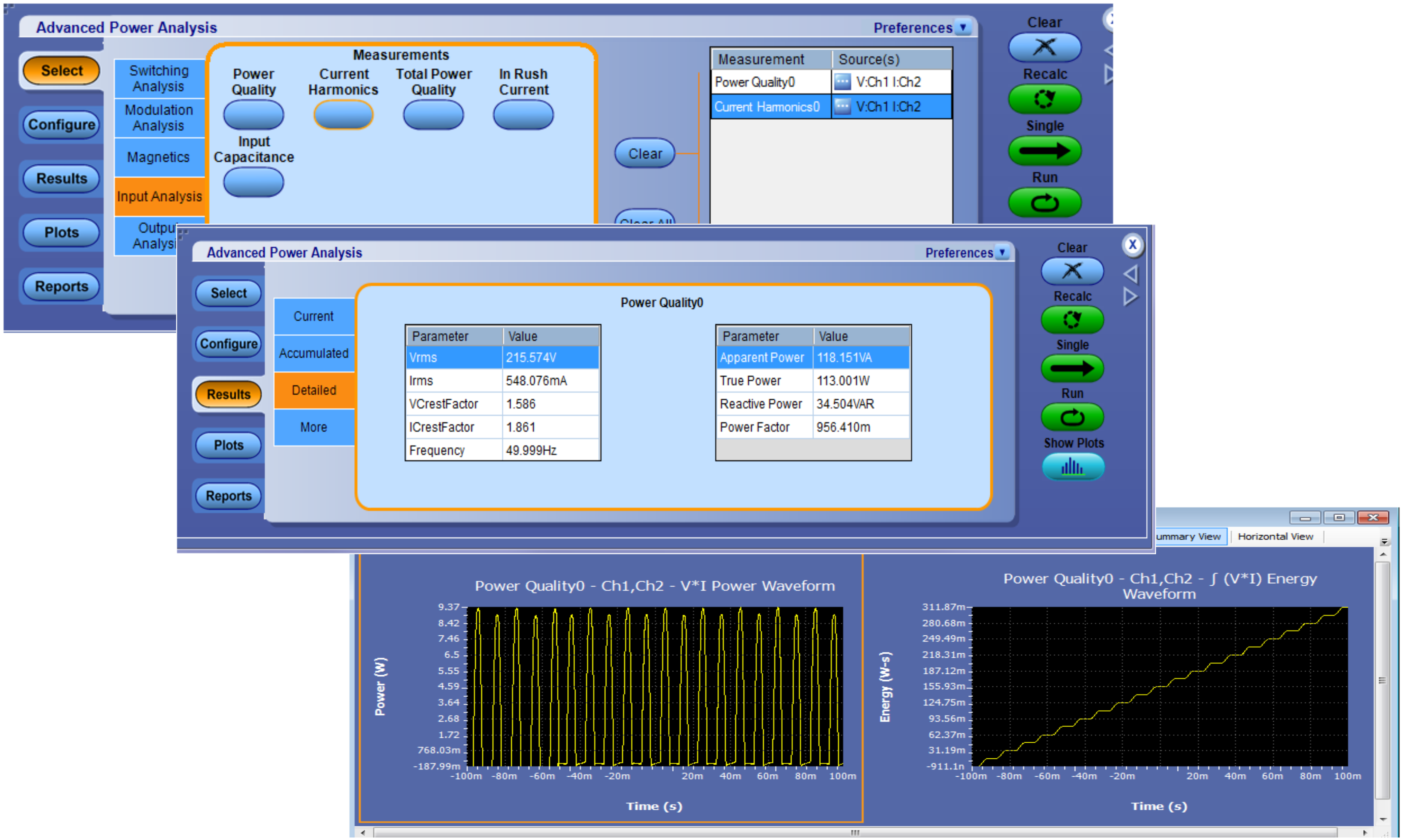
- Power quality measurements
  - Selection → Configure → Single → Results Summary & Detailed → Plots



Tektronix®

Input Analysis

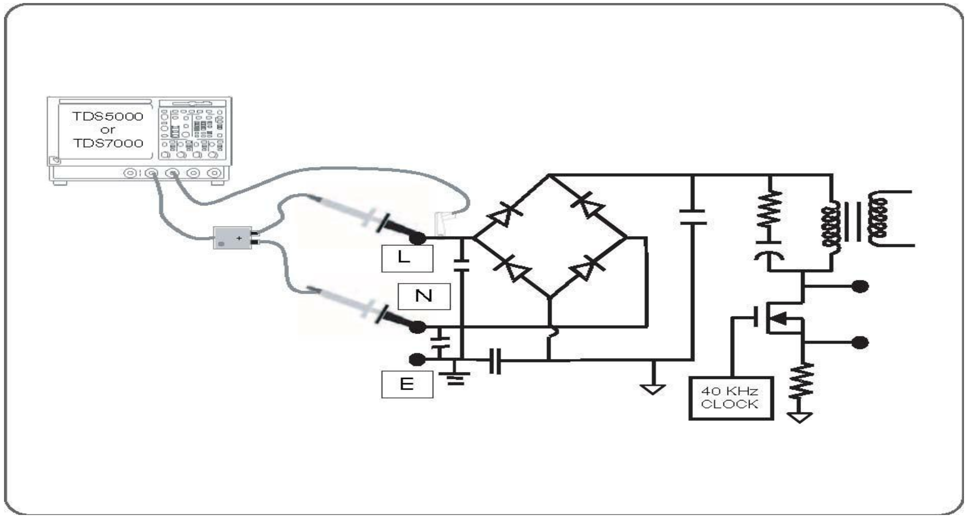
- Power quality measurements
  - Selection → Configure → Single → Results Summary & Detailed → Plots



Current Harmonics and Pre-Compliance Measurements

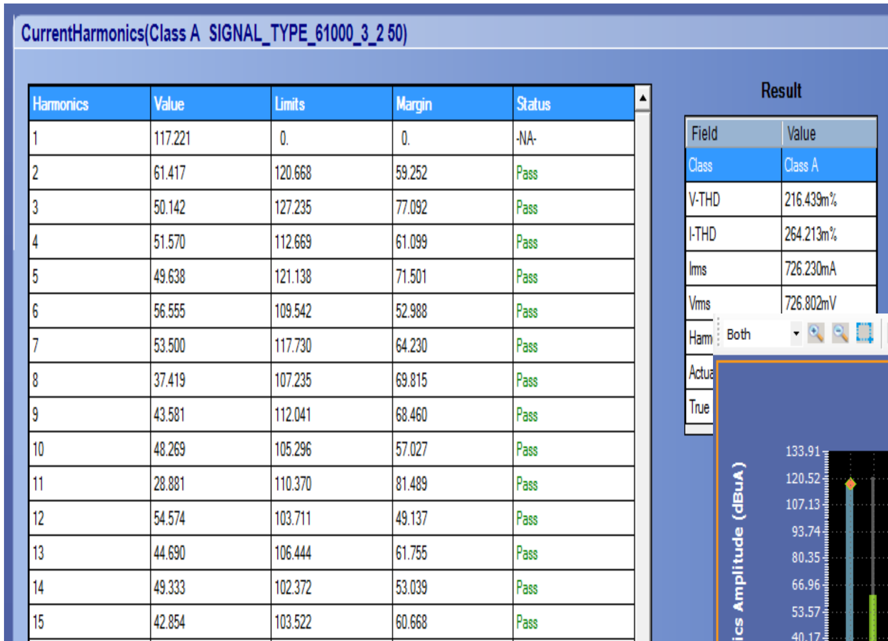
Class A	**Balanced three phase equipment, household appliances, tools , excluding portable tools, dimmers for incandescent lamps, audio equipment**	**Defined by IEC**
Class B	**Portable tools, arc welding equipment, which is not professional equipment**	**Defined by IEC**
Class C	**Lighting equipment**	**Dynamic**
Class D	**Personal computers , LED TV and monitors, driving power less than or equal to 600W**	**Dynamic**

Pre-compliance test setup.



Tektronix®

Current Harmonics and Pre-Compliance Measurements



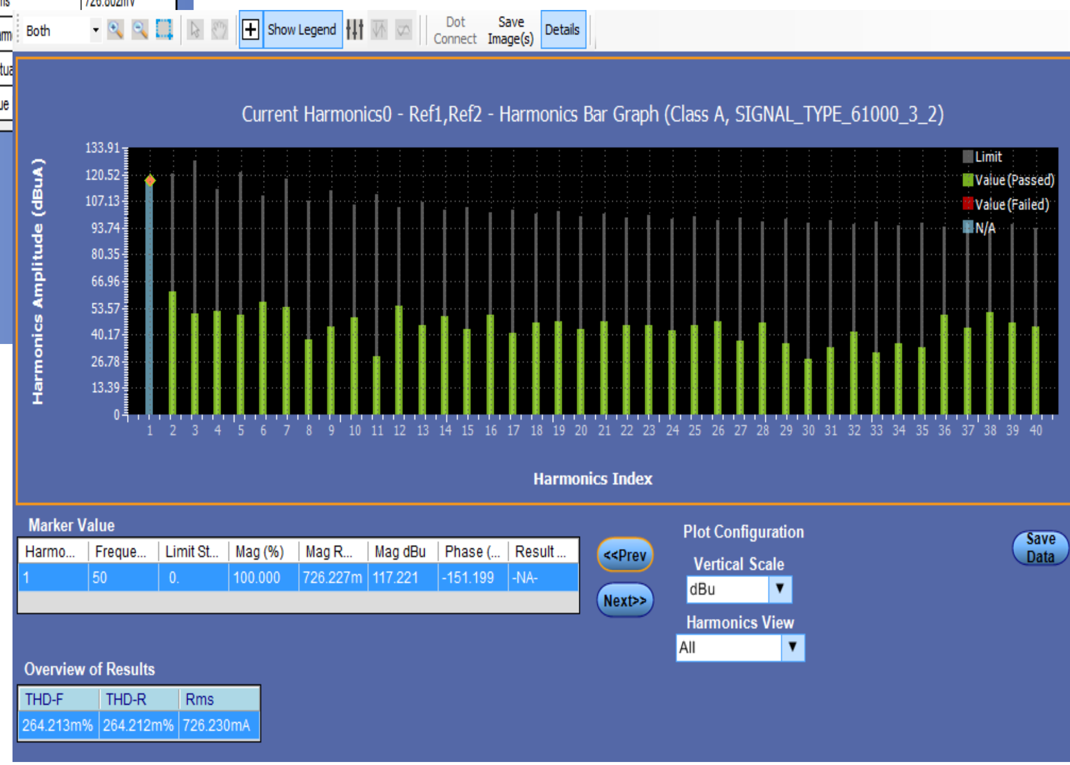
CurrentHarmonics(Class A SIGNAL_TYPE_61000_3_2 50)

Harmonics	Value	Limits	Margin	Status
1	117.221	0.	0.	-NA-
2	61.417	120.668	59.252	Pass
3	50.142	127.235	77.092	Pass
4	51.570	112.669	61.099	Pass
5	49.638	121.138	71.501	Pass
6	56.555	109.542	52.988	Pass
7	53.500	117.730	64.230	Pass
8	37.419	107.235	69.815	Pass
9	43.581	112.041	68.460	Pass
10	48.269	105.296	57.027	Pass
11	28.881	110.370	81.489	Pass
12	54.574	103.711	49.137	Pass
13	44.690	106.444	61.755	Pass
14	49.333	102.372	53.039	Pass
15	42.854	103.522	60.668	Pass

Result

Field	Value
Class	Class A
V-THD	216.439m%
I-THD	264.213m%
Irms	726.230mA
Vrms	726.802mV
Harm	
Actua	
True	

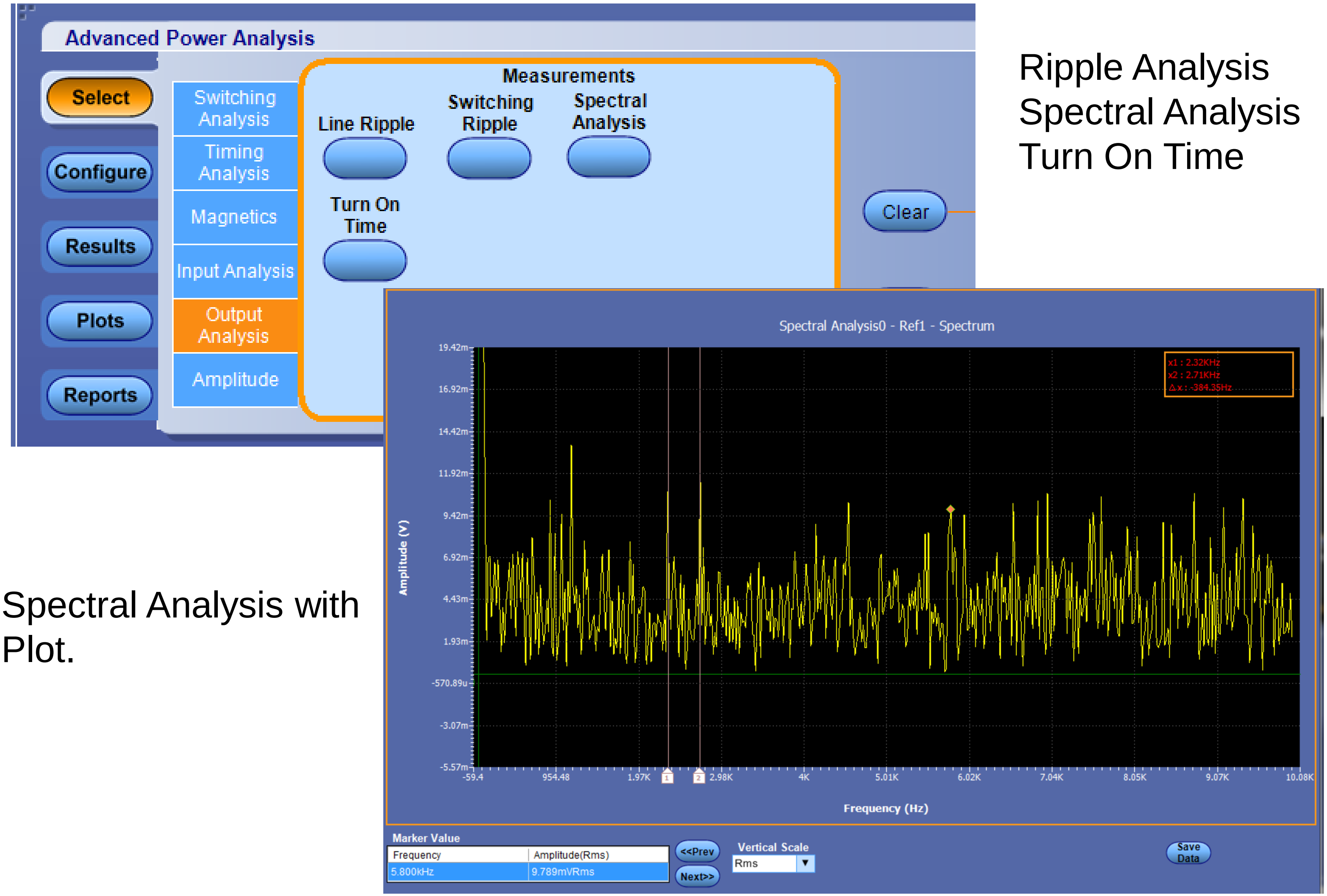
CH Bar graph with Pass/Fail results



Total harmonic distortion is calculated using all, even or odd harmonics

Tektronix®

OutPut Analysis



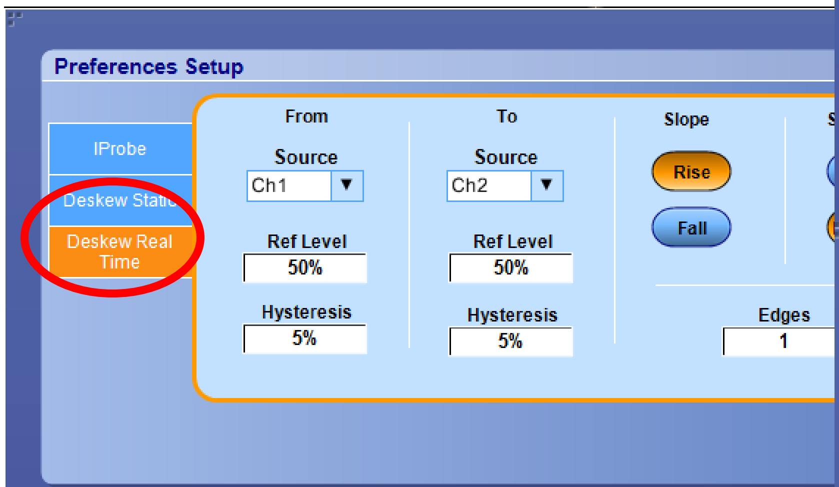
Ripple Analysis
Spectral Analysis
Turn On Time

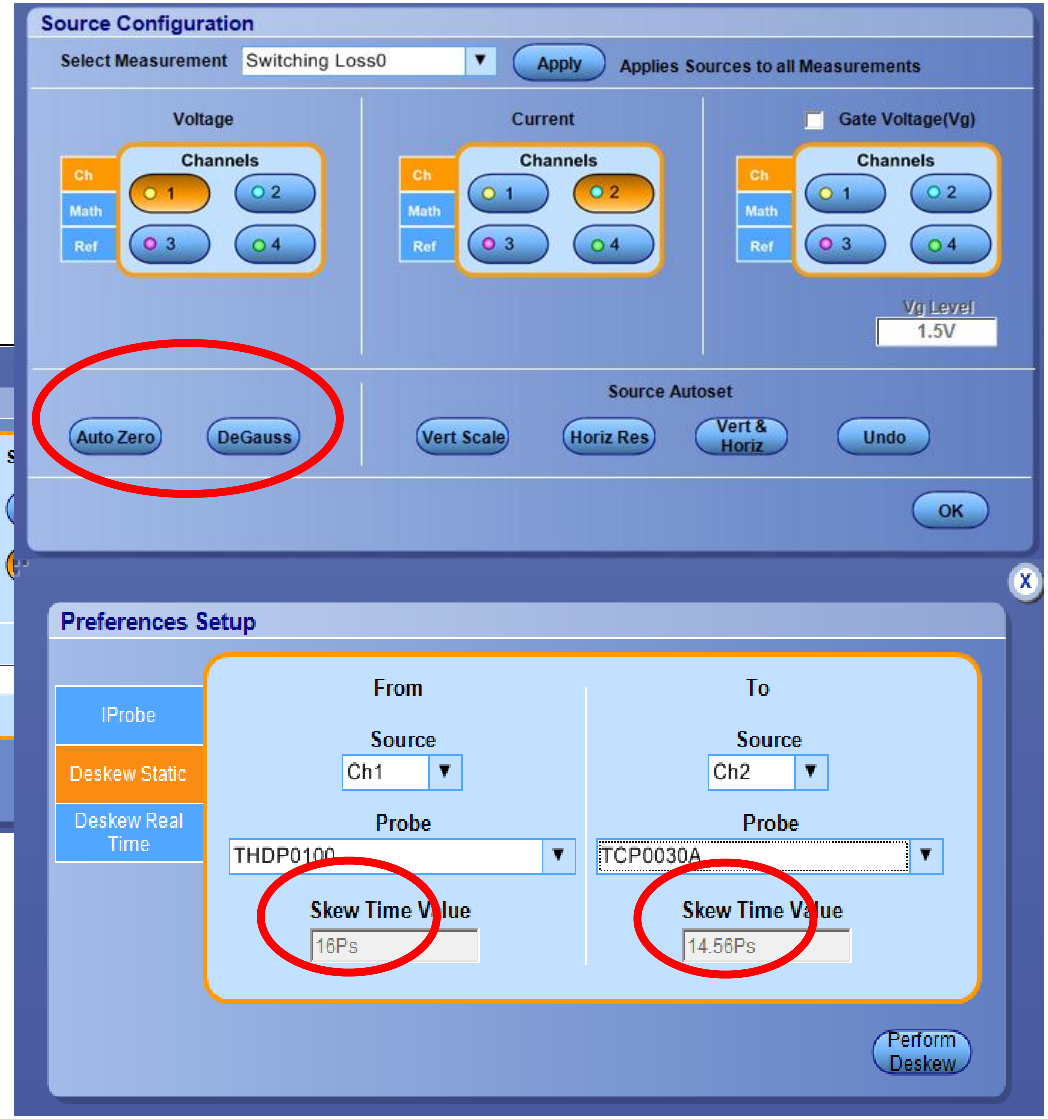
Spectral Analysis with Plot.

Tektronix

Auto degauss and Auto deskew features

- Auto Degauss
- Auto De skew
- Auto Zero
- Auto detection of Probes





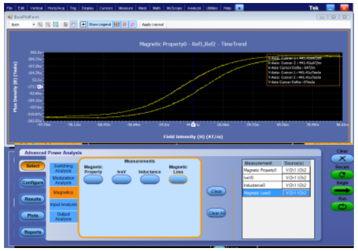
Tektronix®

DPOPWR Factsheet

Advanced Power Measurement and Analysis software

Recommended Scope Models and Software Options

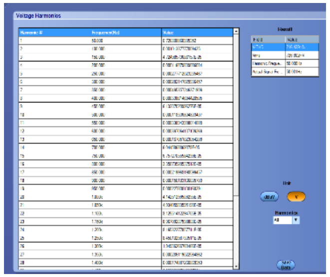
Model	New Instrument Orders	Product Upgrades	Floating Licenses
MSO/DPO5000B Series	Opt. PWR	DPO-UP Opt. PWR	DPOFL-PWR
DPO7000C Series	Opt. PWR	DPO-UP Opt. PWR	DPOFL-PWR
DPO/MSO70000C/DX Series	Opt. PWR	DPO-UP Opt. PWR	DPOFL-PWR



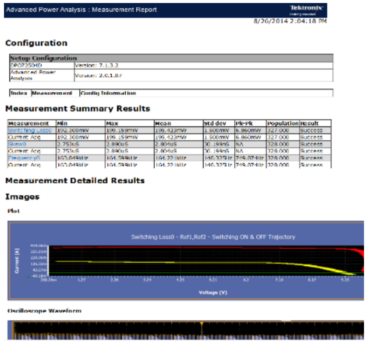
Multiple measurements can run at the same time

Recommended Probes and Accessories

	MSO/DPO5000B, DPO7000C Series	MSO/DPO70000C/DX Series
Advanced Power Measurement SW	Opt. PWR (DPOPWR)	Opt. PWR (DPOPWR)
AC/DC current probes	TCP0030A, TCP0150, TCP0020	TCP202/A with TCA-1MEG, Or TCP0020 with TCA-VPI50
Differential probes	TDP0500, TDP1000	P6251 with TCA-BNC
High-voltage differential probes	THDP0200/0100, TMDP0200	P5200A/P5202A/ P5205A/P5210A with TCA-1MEG, Or TDP1000/500 with TCA-VPI50
High-voltage passive probes	P5100A, P6015A	P5100A or P6015A, with TCA-1MEG
Probe deskew accessories	TEK-DPG and 067-1686-02	TEK-DPG and 067-1686-02
Power solution bundle	PS2 or PS3 *	



Current / Voltage Harmonic Tabular Results



Single printable test report

* Power Bundle Options, which offer significant savings on standard configurations of power probes, accessories, and software
*New DPOPWR requires WIN7-64 bit OS Scopes.

KEITHLEY
A Tektronix Company

Tektronix®

Power Analyzer- Key Test Applications/Needs

- Design, development and test of any single phase electrical or electronic product
  - **Power Supplies & Chargers**
  - UPS and Generators
  - Audio-visual & network devices
    TV, DVD, Recorders, Set-top boxes, WI-Fi modems and routers.
  - Appliances
    Washing machine, refrigerator, vacuum cleaner
  - Office equipment
    Computers, printers
  - Lighting
    Lamps and luminaires. LED and Fluorescent.

- Improved measurement accuracy
  - Power conversion efficiencies >95%
- Higher measurement bandwidth
  - Faster switching speeds
  - New technologies. GaN, SiC
  - Electric Vehicle : IPT
- Very low current measurements
  - e.g., Standby power for consumer electronics
- Evolving standards & regulatory requirements
- Learning curve for instrumentation
  - Setup & configuration specific to each application
- Data transfer, analysis, reporting

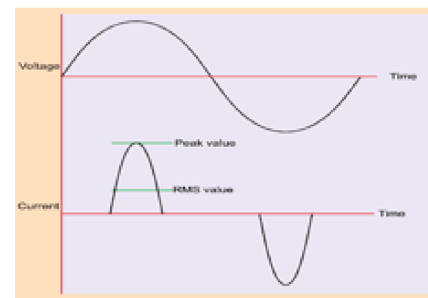
KEITHLEY
A Tektronix Company

Tektronix®

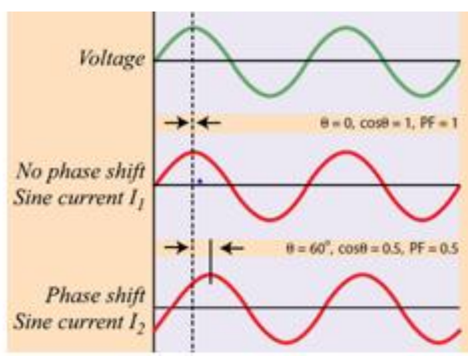
Basic AC Measurements

- RMS - Root Mean Square
- Real Power – True Power – Watts
- Apparent Power – VA or Volt-Amps
- Reactive Power – VAr or Volt-Amps Reactive
- Power Factor
- Peak value and Crest Factor
- Harmonic Distortion

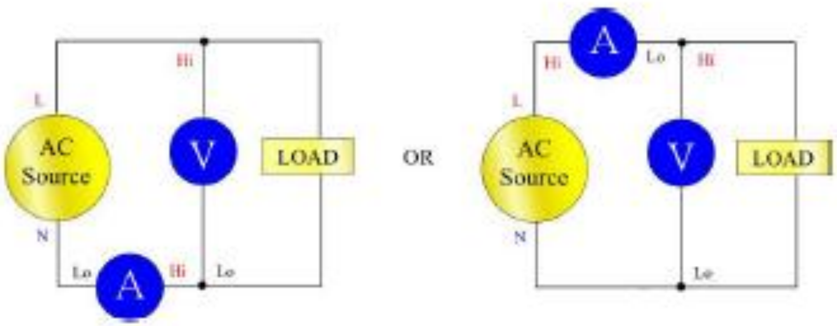
$$Crest\ factor = \frac{Peak\ value}{RMS\ value}$$



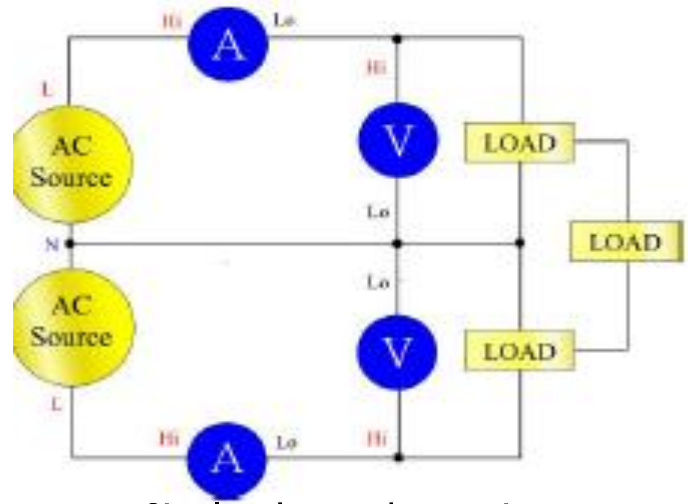
$$Power\ factor = \frac{Real\ power}{Apparent\ power}$$



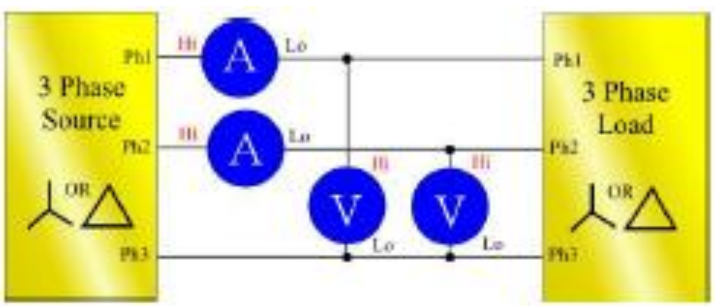
Wiring for Single/Multiphase measurement



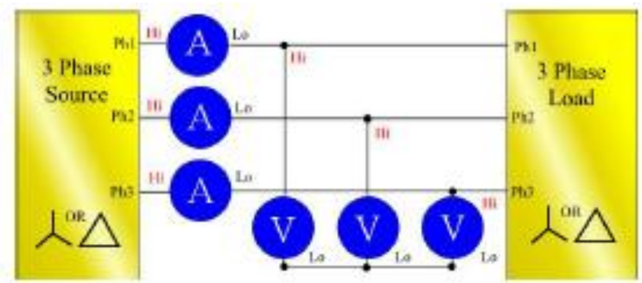
<Single-phase, two-wire and DC measurement>



<Single-phase, three-wire>



<Three-phase, three-wire>



<Three-phase, three-wire, select 4 wire>

Power Measurements of Wireless Charging Systems

- Wireless Charging, also know as Inductive Power Transfer (IPT), is a developing technology
- Prime application is to charge battery operated devices without contact.
- Devices that can be charged : include cellphones, tablets and laptop computers.
- Wireless charging techniques : very convenient since there is no physical connection to make and the device under charge is instantly portable.
- The technology is now being advanced to charge electric vehicles and since charging points could be widespread

- *IPT:*

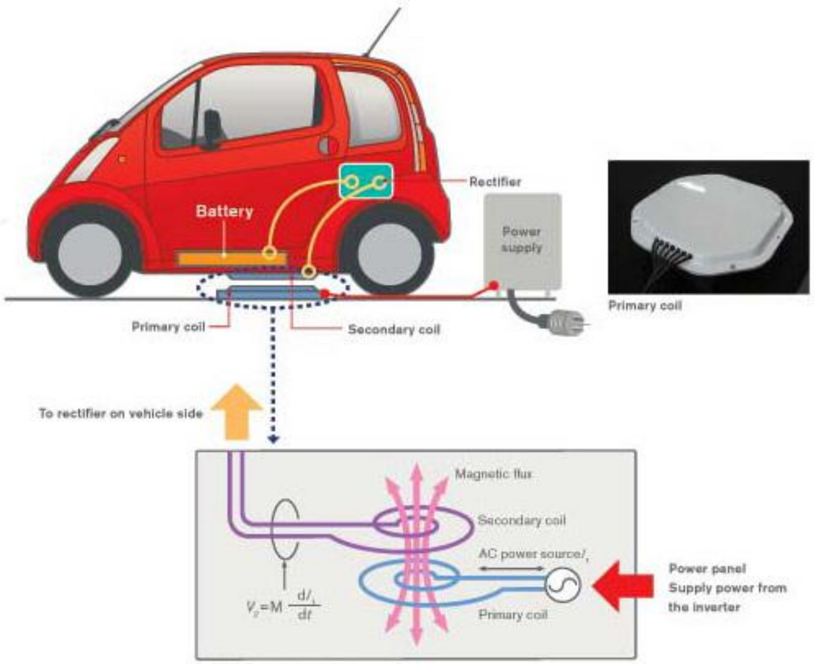
-The technology employs two coils of wire.

- One (the primary or transmit coil) is fixed to the floor and the other (the secondary or receiver coil) is fitted to the underside of the electric vehicle.

-The circuit is that of a simple transformer

IPT in Electric Vehicle

- The circuit operates at high-frequency (20kHz to 100kHz +).
- The primary controller (or power supply) operates from the AC line and generates a controlled AC current in the primary at the desired frequency.
- The secondary controller contains an impedance matching network for maximum power transfer at resonance and a to charge the vehicle battery.



Principle schematic diagram

<Wireless charging for Smart phone>

Power Measurements

- To achieve the overall benefits that electric vehicles provide IPT charging systems must operate efficiently
- An overall efficiency of 90% or more is desired.
- **IPT designers must optimize the conversion efficiency and accurate power instrumentation is required to validate the small incremental efficiency gains obtained during development and during final test.**
- Power measurements include:

Primary controller:

- Input power, volts and amps
- Input Power factor
- Input Harmonics and THD
- Output power, volts and amps
- Output frequency
- Output harmonics and THD
- Efficiency

Secondary controller:

- Input power, volts and amps
- Input frequency
- Input harmonics and THD
- Output power, volts and amps
- Output Ampere-hours, Watt-hours

Coils:

- Efficiency obtained for the primary and secondary controller measurements.

Standby Power

- “Standby power is the power used while an electrical device is in its lowest power mode.”
  Lawrence Berkley National Laboratory.

Examples of products in Standby

Laptop / Tablet / Phone charger connected to the AC line but not charging

Domestic appliance with a clock

Video or Set-top box inactive waiting for remote control

Why is Standby Important?

- The power is small. Less than 1 or 2 watts.
- There are many appliances operating in standby continuously.
-

> Over a year, a microwave oven uses more energy running its clock than it does cooking.

- The cumulative effect is that standby power accounts for an estimated **5 to 10%** off total household electricity consumed in developed countries. (Source: LBNL)

Global energy consumption will grow **53%** between now and 2035

-US Energy Information Administration

- **Trend #1:** Government regulations to reduce power draw
  - Energy Star
  - California Energy Commission
  - European Directive 2005/32/EC
  - Clean Energy Act
- **Trend #2:** Increasing popularity in battery-driven devices
- **Impact:** Our customers must increase efficiency in power module, driving change in design techniques and test requirements

KEITHLEY
A Tektronix Company

Tektronix®

Full Compliance IEC62301 Ed.2/ Standby Power compliance

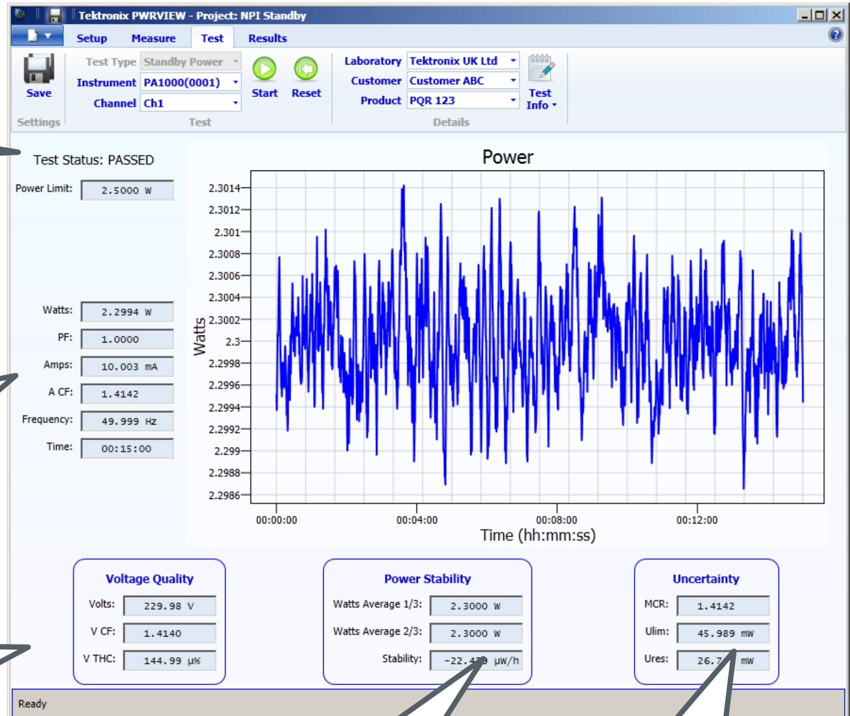
PASS / FAIL

Measurements

Every measurement is recorded simultaneously with a time stamp.

Voltage Quality

Voltage harmonics and THC recorded during the test.



Stability

The slope of the least-squares linear regression through the second 2/3 of the power measurements is displayed in real time.

Uncertainty

The required uncertainty U LIM and the actual uncertainty of the measurement U RES are calculated and displayed in real time.

- For both PA4000 and PA1000
- 1A shunt built in to both products
- Included in the FREE PWRVIEW software

- Simultaneous voltage quality measurements.
- Live stability check
- Calculates MCR and U automatically
- Great reporting.

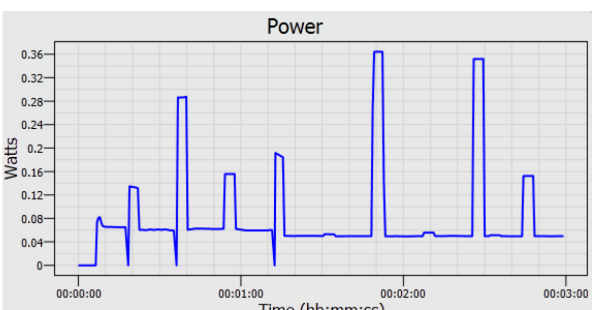
KEITHLEY
A Tektronix Company

Tektronix

Measurement Concerns

Problem

- **Low power and current.**
  < 1mA @230V
- **Highly distorted waveforms.**
  Since power supplies operating at low load often draw very high crest-factor current.
- **Low power factor.**
  because the current may be predominantly capacitive, through the power supply EMC filter.
- **Irregular power draw.**
  When the power supply is in burst or hiccup mode, minimizing input power.



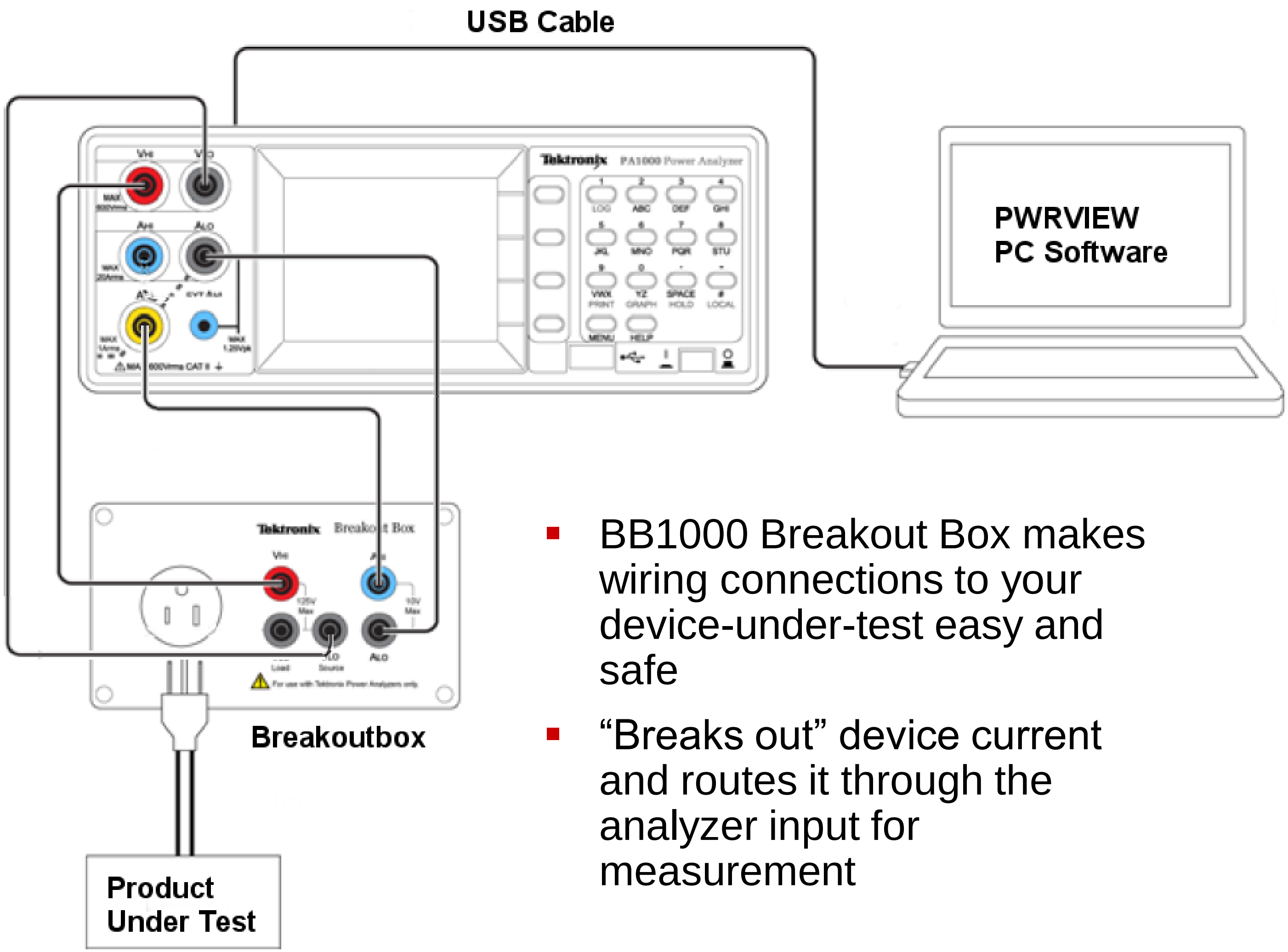
Tektronix Solutions

- **Low input ranges**
  1A shunt.
- **Peak Ranging**
  Guarantees measurements with a crest factor up to 10.
- **Precision power analyzer**
  Voltage and current phase delay minimized by analog design.
- **Continuous sampling and long averaging.**
  No missing data.

KEITHLEY
A Tektronix Company

Tektronix

Making Connections – Vlo Source



- BB1000 Breakout Box makes wiring connections to your device-under-test easy and safe
- "Breaks out" device current and routes it through the analyzer input for measurement

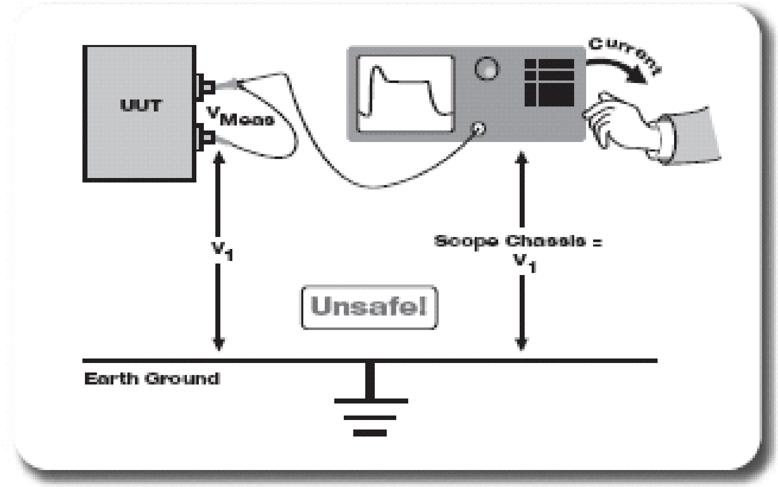
Measurement Tips

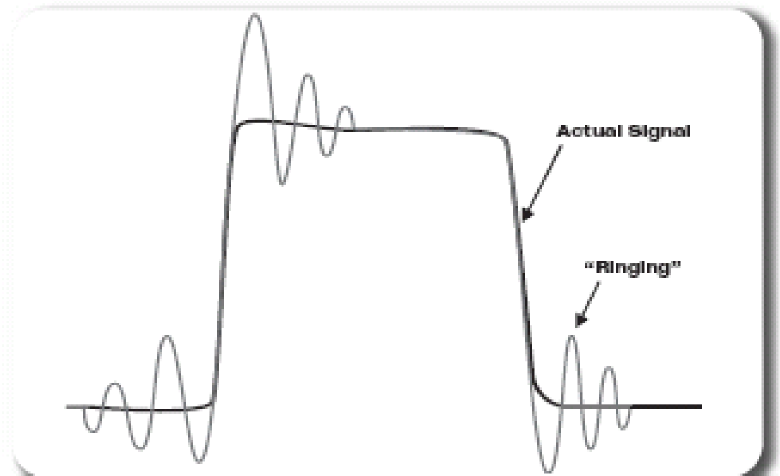
Tektronix®

Tektronix®

Understanding Differential/Floating Measurements

- Differential measurements measure the difference in voltage levels at two points. The measurement is made with respect to a common reference point.
- Floating measurements are those where neither test point is at ground potential.
- ***DO NOT FLOAT YOUR OSCILLOSCOPE!***
  - Shock hazard to operator.
  - Oscilloscope's power transformer insulation is stressed, which may lead to future shock and fire hazards.
  - Measurements are inaccurate, corrupted by ringing and noise.





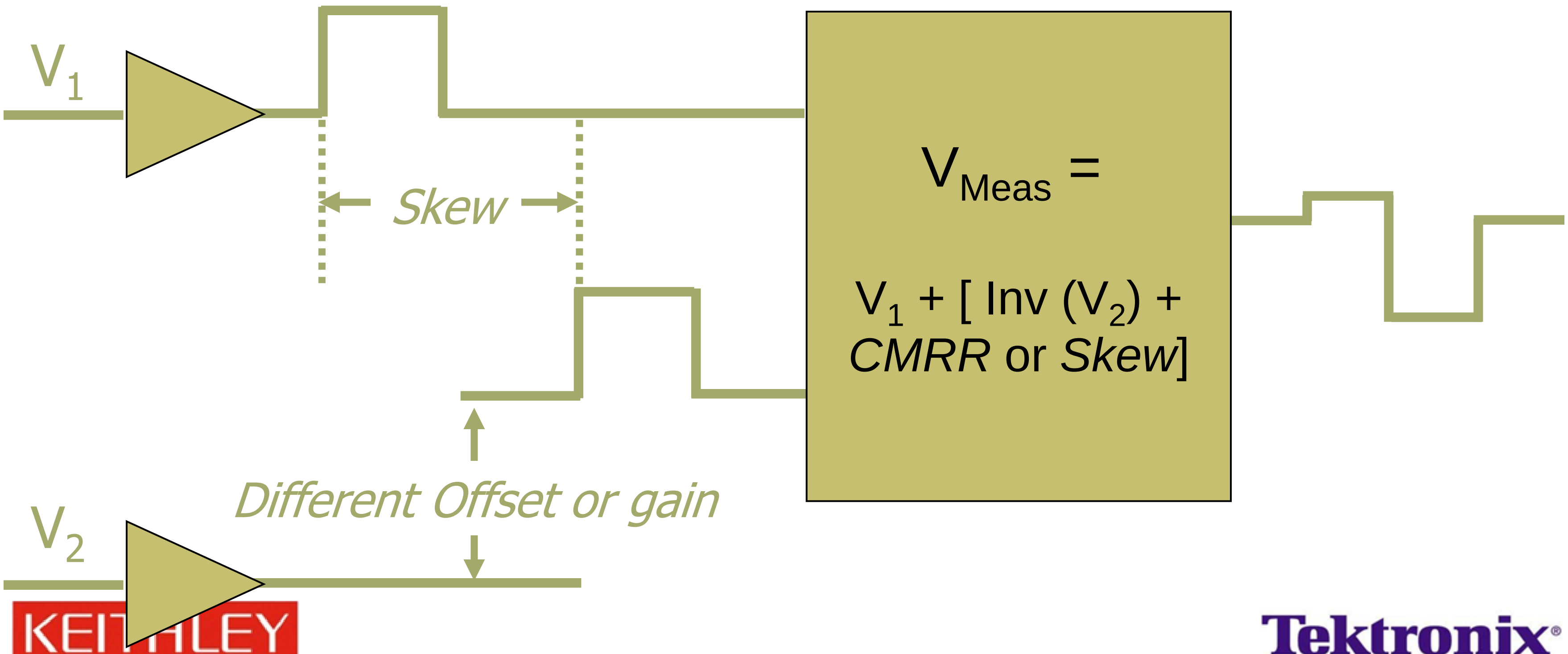
Making Differential/ Floating Measurements

- Method 1: Using two single-ended (usually passive) probes
- The difference signal is obtained by measuring both signals to ground and using the oscilloscope's math function to subtract one from the other.
  - Issue #1: Poor common-mode rejection
    - Inaccurate measurement
    - Noisier measurement
  - Issue #2: Skew
    - Amplitude errors
    - Timing errors
- Method 2: Use a differential probe (preferred)
  - Eliminate the need for any kind of ground connection
  - Provide a high CMRR over a broader frequency range
  - Eliminate most noise concerns.

Tips and Tricks

Differential vs. Pseudo-differential

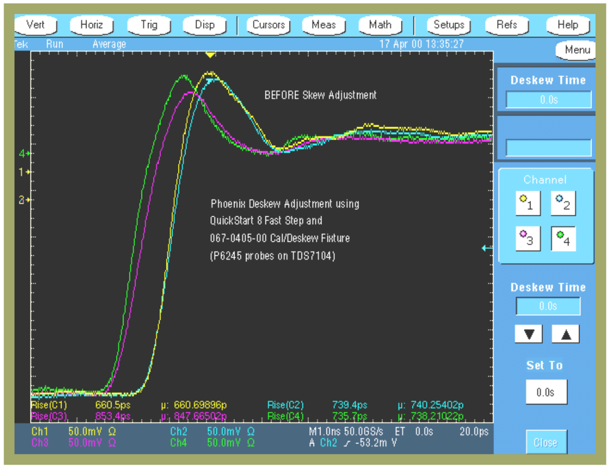
- Poor CMRR
  - Inaccurate measurement (combination of offset and gain)
  - Noisier measurement
- Skew
  - Amplitude and timing errors

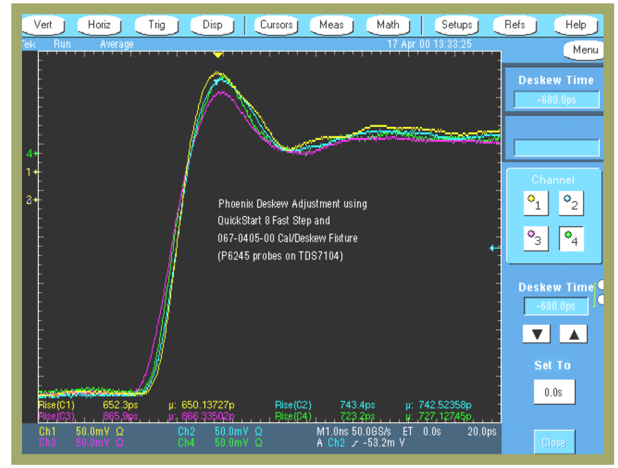


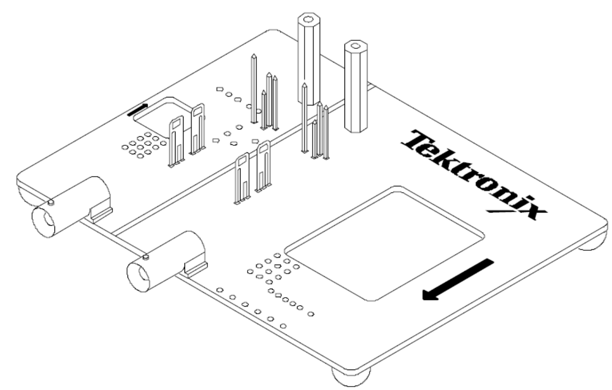
Tips & Tricks

Deskew and Propagation Delay

- Deskew accounts for timing/propagation delay
- Include probe adapters in deskew adjustment





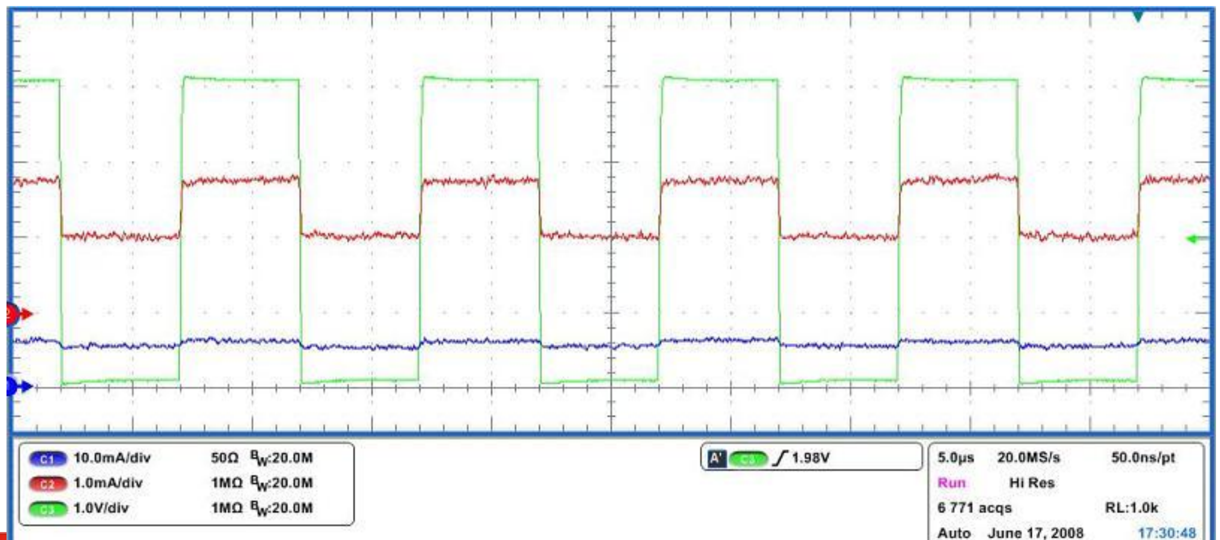


Deskew Fixture

Tips & Tricks

Current Probe Wire Wrapping & Lead Inductance

- Longer wire loops make it easier to connect the probe
  - Rule of Thumb: 20 nH per lead inch
  - Limits current and masks high frequency content
- Wire wrapping can be used to increase sensitivity with trade-offs
  - Divide sensitivity by number of turns (i.e. 1 mA per div / 10 turns → 100 uA per div)
  - Inductance: $L = (\text{number of turns})^2$
  - Bandwidth degrades (for 10 turns, reduced to < 1 MHz)



KEITHLEY
A Tektronix Company

Tektronix

Tektronix®